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INDUSTRIAL EDUCATION SERIES

THE PROPERTIES AND USES OF WOOD

PREPARED IN THE
EXTENSION DIVISION OF
THE UNIVERSITY OF WISCONSIN

BY

ARTHUR KOEHLER, B. S.,

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So the Deacon inquired of the village folk
Where he could find the strongest oak,
That couldn't be split nor bent nor broke,—
That was for spokes and floor and sills;
He sent for lancewood to make the thills;
The crossbars were ash, from the straightest trees;
The panels of whitewood, that cuts like cheese,
But lasts like iron for things like these;
The hubs of logs from the "Settler's ellum,"
Last of its timber,—they couldn't sell 'em,
Never an ax had seen their chips,
And the wedges flew from between their lips,
Their blunt ends frizzled like celery-tips;)
Step and prop-iron, bolt and screw,
Spring, tire, axle, and linchpin too,
Steel of the finest, bright and blue;
Thoroughbrace bison-skin, thick and wide;
Boot, top, dasher, from tough old hide
Found in the pit where the tanner died.
That was the way he "put her through."
"There!" said the Deacon, "naow she'll dew!"

ONE-HOSS SHAY—*Oliver Wendell Holmes.*

18562

PREFACE

In this book an attempt is made to present in as non-technical a manner as is consistent with clearness and accuracy, the more important facts concerning the properties of wood and how these properties affect its utilization. Of late years there has been considerable demand for more definite information concerning timber than ordinarily can be obtained in practice or in the trade. Instead of general opinions and impressions as to strength, shrinkage, durability, etc. the lumber manufacturer, dealer, and user want the results of carefully conducted tests. This desire for more information is prompted largely by the increasing price of lumber which is due principally to the rapid depletion of our forests.

A large part of the information contained herein has resulted from researches of the Forest Products Laboratory maintained by the United States Forest Service in cooperation with the University of Wisconsin. This Laboratory is the largest and best equipped of its kind in the world. During its fourteen years of existence it has accumulated a vast fund of facts and data concerning wood. To get this information together, condense the more important matter and leave out much of the detail, though interesting and valuable, was no small task. Throughout the volume the author has constantly striven for accuracy in so far as it was possible to obtain accurate data. In some cases the data presented are old or based on a meager number of tests, but they are in every case the latest and most authentic available. In many cases references are given so that the reader may follow up the subject if he chooses, but no attempt is made to give a complete bibliography of any subject. Only the more important and available publications have, as a rule, been cited.

Most of the book is devoted mainly to a discussion of the properties of wood. The discussion about the utilization of wood comprises only that minimum which shows that the uses to which wood in general or any particular species of wood are put depend ultimately on the properties of wood. By knowing the properties of a material its satisfactory uses can be predicted.

The illustrations used in this book are obtained from various sources, acknowledgment of which is made in the text.

The author wishes to express his sincere thanks to the following persons for helpful suggestions and for reviewing the manuscript in part: J. A. Newlin, L. J. Markwardt, H. D. Tiemann, Eloise Gerry, S. D. Wells, E. E. Hubert, C. J. Humphrey, G. M. Hunt, L. F. Hawley, Arthur Upson, and Ernest Bateman of the Forest Products Laboratory; S. J. Record, Professor of Forest Products, Yale Forest School; and P. R. Hicks, Secretary-Manager, Service Bureau, American Wood Preservers' Association.

ARTHUR KOEHLER.

MADISON, WISCONSIN,
March, 1924.

INTRODUCTION

We are prone to think of timber in its various forms as a gradually passing material of construction and manufacture. On every hand we see evidences of steel, stone, or concrete being used in place of wood. However, the fact remains that the annual consumption of timber in this country has decreased very little during the last two decades and that decrease was due principally to the increasing cost of lumber. We still use annually the equivalent of about 50 billion board feet of wood in all forms not including firewood.

At the present rate of growth and consumption the next generation will witness a severe timber famine which will be felt in the home, on the farm, in the shops, in the office, in transportation, and in recreational activities. It is only by more intensive forestry practice, fire prevention, and closer utilization of what timber has grown to merchantable size that a stringent shortage of timber can be averted. This book deals with facts about the characteristics and properties of wood which can be applied by the forester in selecting the more useful kinds of timber to grow, and by the lumberman, manufacturer, dealer, and consumer in promoting the more efficient utilization of forest products.

That the present methods of utilizing wood in its various forms are far from efficient is shown by the large percentage of waste in logging, sawing, seasoning, manufacture, and chemical conversion; the improper choice of species for many purposes; and the unnecessarily large losses by fire, marine borers, insects, stain, and decay. This deplorable situation calls for serious consideration.

The more economical use of timber can be accomplished through application of accurate information regarding its possibilities and limitations, the relative merits of the different kinds of wood and their adaptability to different kinds of treatment. For example, when it was found from tests that the red heartwood of hickory is just as tough as the white sapwood, prejudice against "red hickory" subsided and more thorough utilization of the rapidly diminishing supply of hickory resulted. When the

use of red gum became satisfactory through proper seasoning methods, its value increased from that of an unmarketable forest tree to that of a high-grade furniture wood. With the development of preservative treatment of timber it has become possible to use for railway ties and fence posts many non-durable and less valuable woods, such as red oak, ash, lodgepole pine, and white fir, in place of a very limited number of durable species, such as white oak, longleaf pine, cedar, and redwood.

Closer utilization, better manufacturing methods, and prolonging the life of what is used will reduce the annual timber consumption to a considerable extent, thereby postponing, or, together with better forestry practice, avoiding altogether a timber famine. Closer utilization of forests products will have the additional advantage of increasing the profits in the lumber industry, which in turn will make it more profitable for the timber owner to grow more timber.

Furthermore the losses in manufacture are a total economic loss which must be borne by someone, usually the consumer. With closer and better utilization of materials it is possible to reduce manufacturing costs and produce cheaper goods. Cheaper goods with reasonable profits and wages are an approach toward ideal economic conditions.

Better selection of materials and improved manufacturing processes also mean the production of more satisfactory products. This is of direct benefit to the consumer and eventually results to the advantage of the manufacturer. The builder who sees to it that his lumber is carefully selected and properly seasoned, and that untreated and non-durable wood is not used in situations which favor decay, is building not only for the advantage of his client but also for the good of his own reputation and the permanency of his own interests.

A secondary purpose of this book is to increase interest in wood by more widely disseminating information about it. The more one knows about a subject the greater his interest in it becomes. It has been well said that he who would bring back the wealth of the Indies must take the wealth of the Indies with him. Greater interest in wood on the part of the wood-worker will mean that he will be more careful of it and that he will do his work better, which is of advantage to himself, his employer, the consumer of the product, and the country at large.

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THE PROPERTIES AND USES OF WOOD

CHAPTER I

THE STRUCTURE OF WOOD

The uses for which wood is suitable depend upon its properties, that is, upon the way it behaves under various conditions. Such properties as strength, lightness, workability, and freedom from corrosion make wood admirably fitted for a large number of uses; while the ease with which it burns, its susceptibility to decay, and shrinking and swelling limit the uses to which it may be put to advantage.

The properties of wood are determined by its chemical composition, that is, what it is composed of; and its physical structure, that is, how it is built up. Both the chemical nature and the physical nature of wood are fundamentally different from those of other common structural materials. Except for variation in the small amounts of infiltrated materials, the chemical composition is approximately the same in all kinds of woods; that is, all woods are composed mostly of carbon, hydrogen, and oxygen in definite proportions. The structure, however, varies considerably and is responsible principally for differences in the properties of the different kinds of woods, except in so far as color, odor, durability, extracts that may be made from the wood, and a few other properties are concerned. The chemical composition of wood and its relation to its properties and uses will be discussed briefly in Chap. VI.

1. Wood Is Built Up of Cells.—Wood, like all other plant material, has a cellular structure. Most of the cells in wood are very much longer than they are wide, and for this reason are called fibers. A typical living cell consists of a wall surrounding

a cavity which contains a soft jelly-like substance called protoplasm in which the life processes are carried on. Figure 1 shows the principal parts of a living cell.

In the wood of living trees comparatively few cells, however, contain living protoplasm. In most of the cells in wood the protoplasm disappears as the cells mature and they become filled with water or air, or with varying proportions of each. Occasionally other materials, as resins, gums, and mineral matter are deposited in the cell cavities. The cells of wood are all grown together tightly forming a more or less coherent but porous material.

The cellular structure is responsible to a large extent for some of the advantages and disadvantages of wood over other structural materials. The cell cavities allow the cell walls to "give" so that nails and screws can readily be driven into lumber, thus affording a comparatively easy means of fastening two pieces together. Because in most commercial woods over one-half of the volume is occupied by cell cavities, their hardness is not so great but that they can be shaped into various forms with simple tools and comparatively little labor. Woods with very small cell cavities and thick cell walls, as lignum-vitæ, are about as hard as horn and are very difficult to work.

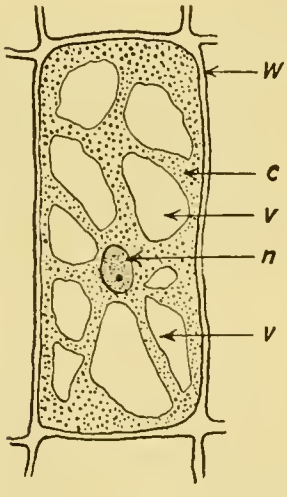


FIG. 1.—A typical living cell: *w*, the cell wall; *c*, cytoplasm; *v*, vacuoles containing cell sap; *n*, nucleus. The cytoplasm and bodies imbedded in it constitute the protoplasm.

Because of the cavities in the cells, most woods, when dry, are fairly light for a given volume. This is of advantage in the manufacture of furniture and other articles requiring a certain size but not great weight or strength.

The cell cavities act as dead air spaces which retard the transmission of heat and sound. This makes lumber especially adaptable for building purposes, since it tends to keep the heat in in winter and out in summer, and makes the building comparatively sound-proof.

Because wood is not a compact homogeneous substance, it absorbs shocks and vibrations to a considerable extent. This makes it particularly suitable for hammer handles, airplanes, and wagon wheels and axles.

The figure in wood, which for some purposes is an important asset, is due largely to differences in the size and arrangement of its various cells, although irregular infiltrations of coloring matter also may add to the figure.

On account of its porous nature, wood, unless very oily or resinous, holds paint so that it will not scale off so readily as when applied to non-porous surfaces, such as metal and stone. Preservatives may be forced through the cells and thus increase the durability of timbers. Glue penetrates the fibers and obtains a hold, making it possible to secure a stronger glue joint in wood than in non-porous materials.

Wood may be separated into its component fibers, which, when felted together can be made into paper, wall board, roofing, etc.

The cells in wood vary in size and shape and in the functions they perform. Some serve primarily to conduct sap, others to store food, and others to give strength to the tree. Collectively, the different kinds of cells are spoken of as "elements." A certain size and arrangement of the elements, varying within certain limits, are characteristic of each species or groups of species, and help in identifying the different kinds of woods and in judging their qualities.

2. How a Tree Grows.—A tree grows by forming new cells under the bark and at the tips of the branches and roots each growing season, thus increasing its diameter, height, and extent of root system each year. The new cells are formed by the division of certain delicate cells functioning solely for this purpose. The growing region under the bark is known as the *cambium*. This is shown in Fig. 2. As an initial cambium cell divides, one of the two new cells formed grows to larger size and becomes thicker walled, forming either a wood element if the inner one develops, or a bark element if the outer one develops. The other cell formed by the division of the parent cell does not develop into other tissues, but after increasing in size it again divides producing a wood or bark element and so on, always leaving undeveloped cells to continue the process of division. Most palms do not have a cambium but attain a certain diameter by the expansion of the cells formed at the growing apex. The trunks of each species are of about the same diameter, but vary considerably in height.

In the spring when the cambium is most active and many delicate new cells are formed under the bark it may be ruptured

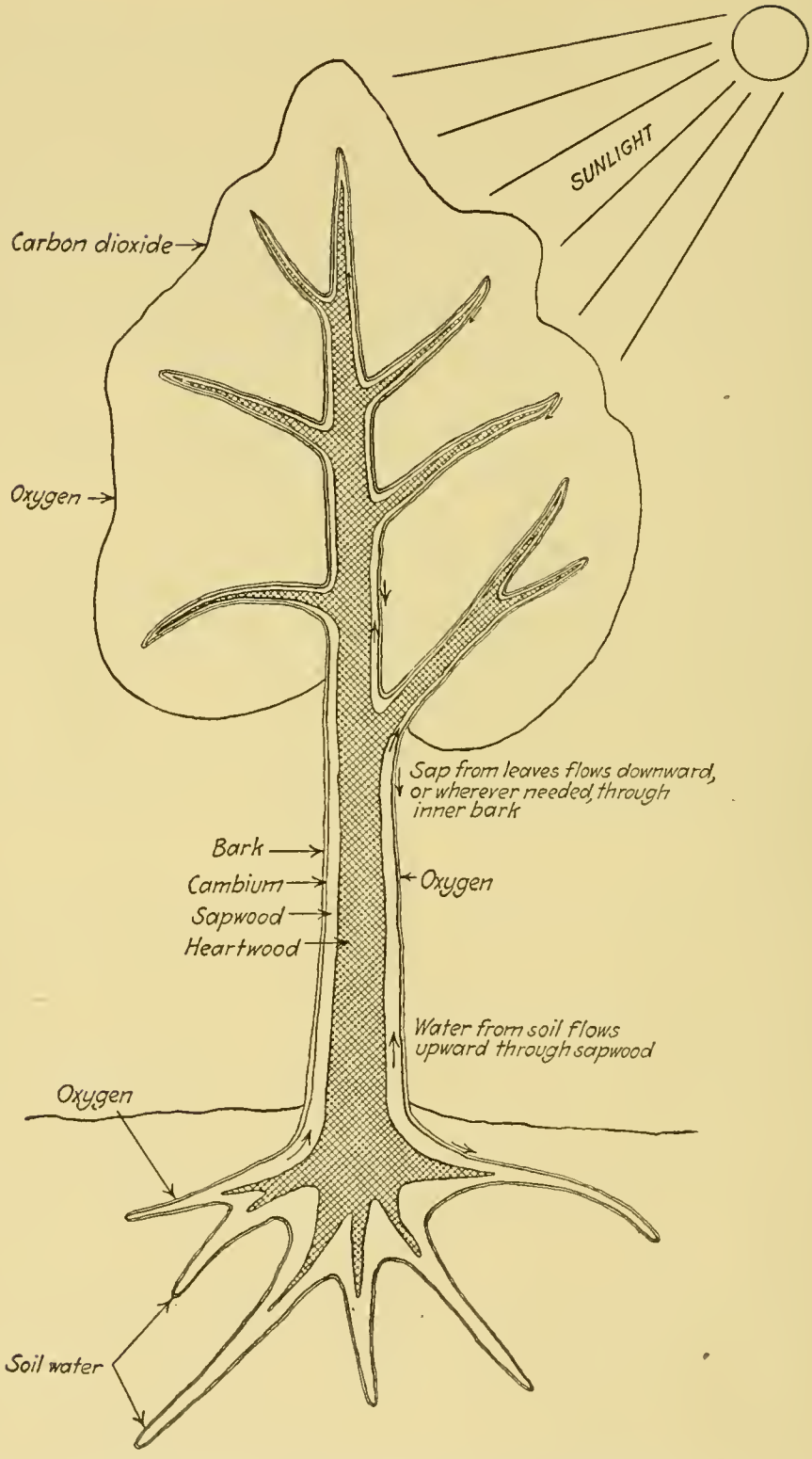


FIG. 2.—Diagram showing the principal parts of a tree, and the source and distribution of materials for food and energy.

with comparative ease and the bark readily separated from the trunk and limbs. In the summer the cambium becomes more or less inactive and hardened. Hence, the little boy makes his whistles in the spring, and tanbark and basket-willow reeds are peeled before the summer is far advanced.

Green logs cut in winter often have enough food stored up in them so that when the warm weather of spring comes on the cambium begins to grow, sometimes making it possible to peel winter-cut logs in the spring fully as well as if they had been cut in the spring.

In a tree, the wood which has been formed previous to the current year does not grow in volume any more. If a nail is driven into the wood of a living tree it will remain at the same level and the same distance from the center of the tree, but ultimately the head may be grown over with new wood. From this it is evident that chipping a pine tree for turpentine or even the death of a tree on the stump cannot materially affect the structure of the wood already formed, although it may cause resin to accumulate in the cells under the injured portion, and it may allow insects and decay to enter, or checks to form.

The material necessary for the formation of new cells is derived mostly from the air in the form of carbon dioxide, and from water in the soil.

The mineral matter taken up in solution by the roots forms a very small percentage of the nourishment of the tree but is absolutely essential to carry on its life processes. The water from the soil passes up to the leaves through the sapwood of the roots, trunk, and branches. In the leaves, by means of sunlight, part of the water combines with the carbon dioxide absorbed by them from the air and the remainder is evaporated. The new compounds formed from the water and carbon dioxide pass to the growing parts through the inner bark and, according to some investigators, through the sapwood. The water passing up through the sapwood and the solutions coming down from the leaves are both commonly spoken of as *sap*. A tree will continue to live for some time after the bark is girdled; but if the sapwood also is completely girdled, it will soon wither and die.

3. Fibers.—Wood fibers are comparatively long, narrow, tapering cells closed at both ends as illustrated in Figs. 3 and 4. The length of the fibers varies from $\frac{1}{25}$, or less, to $\frac{1}{3}$ inch. In the

hardwoods the fibers are smaller, both in length and in diameter, than in the softwoods, or conifers.[1]

The length of the fibers has no relation to the strength of wood as is often supposed. Spruce and redwood are among the longest-fibered woods, but they are not so strong as oak and hickory which have comparatively short fibers. When wood fails in tension, the fibers do not separate from each other as a rule, but they tear apart. Their strength is governed to a large extent, however, by the thickness of their walls.

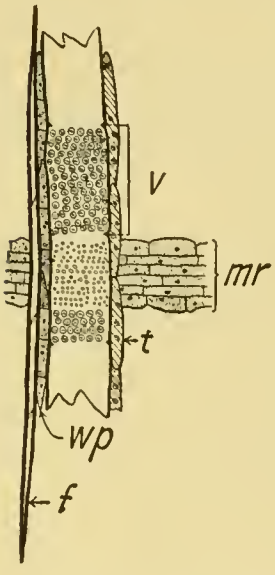


FIG. 3.—Typical elements from the sapwood of white elm magnified 55 diameters. *f*, fiber; *v*, one cell, or segment, of a vessel; *t*, tracheid with spiral thickenings; *wp*, wood parenchyma cells: *mr*, medullary ray cells. The small circles are thin places in the cell walls which facilitate the passage of sap from one cell to another. The wood parenchyma and medullary ray cells are the only ones that retain their protoplasm and are alive after being fully grown.

The fibers usually comprise a large part of the wood. In the hardwoods the fibers serve principally in giving strength to the trunk, branches, and roots; whereas in the conifers they serve the combined function of giving mechanical support and conducting sap. Some hardwoods also have short fiber-like cells which conduct sap. These are illustrated in Fig. 3. Fibers having this dual function have been given the technical name *tracheids*.[2]

[1] By "hardwoods" is meant all native trees with broad leaves, such as oak, elm, and basswood; by "conifers" is meant trees with needles or scale-like leaves, such as pine, fir, and cedar. The terms hardwoods and softwoods, or conifers, are not exactly correct designations for the two large classes of woods; for some so-called softwoods are harder than some so-called hard-woods, and some so-called conifers do not bear cones. Other designations, such as porous and non-porous woods, woods from deciduous and woods from evergreen trees, woods from broad-leaved trees and woods from trees with needles or scale-like leaves, are also inexact because exceptions are found in both classes. The botanical terms, *angiosperms* (meaning seeds inclosed in an ovary), for hardwoods, including palm-like trees, and *gymnosperms* (meaning seeds not inclosed in an ovary), for softwoods or conifers are consistent but are not in common usage.

[2] Since the function of the various wood elements cannot easily be determined they are usually identified by their structure, and, strictly speaking, tracheids are elongated, comparatively narrow, fiber-like elements with closed ends and distinctly bordered pits, whereas true wood fibers have unbordered, or indistinctly bordered pits, by pits being meant the thin places in the cell walls.

4. Pores.—Scattered among the fibers of hardwoods there are cells of comparatively large diameter which have open ends and are set one above the other forming continuous tubes commonly called *pores*, and technically known as *vessels*. Figure 3 shows a side view of some vessel segments of white elm, and Fig. 5 shows cross-sections of the pores in oak and birch. These pores serve to conduct sap from the roots to the leaves. The conifers do not have such pores, but the sap in traveling from one fiber to another must pass through the fiber walls. The hardwoods are often referred to as *porous* woods, while the conifers are called *non-porous* woods, although in another sense all woods are porous, that is, they are made up of hollow cells and absorb moisture.

In coarse-textured woods, or so-called "open-grain" woods, such as oak and ash, some of the pores are plainly visible to the unaided eye, appearing as minute holes on the cross-section and as fine grooves on longitudinal surfaces. In finer textured woods, such as maple and beech, the pores are visible only through a magnifying glass.

The pores may all be of approximately the same size, as in maple, birch, gum, and basswood, in which case the wood is called *diffuse-porous;* or they may be in one or more concentric rows of large pores alternating with a denser layer containing very small pores, as in oak, chestnut, ash, hickory, and elm, in which case they are called *ring-porous woods*. An examination of Figs. 5, 6, and 7 shows the difference between the ring-porous and diffuse-porous woods.

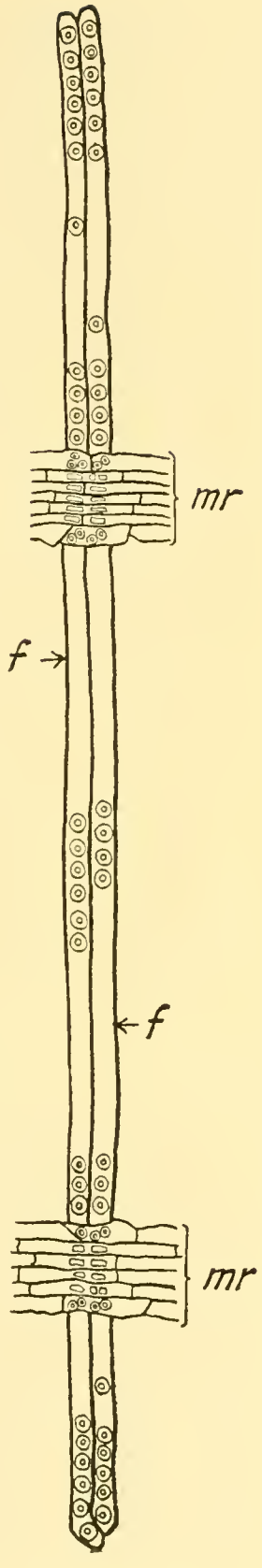


FIG. 4.—Typical elements of the heartwood of white pine, magnified 55 diameters; *f*, fibers (tracheids); *mr*, medullary ray cells (protoplasm no longer present).

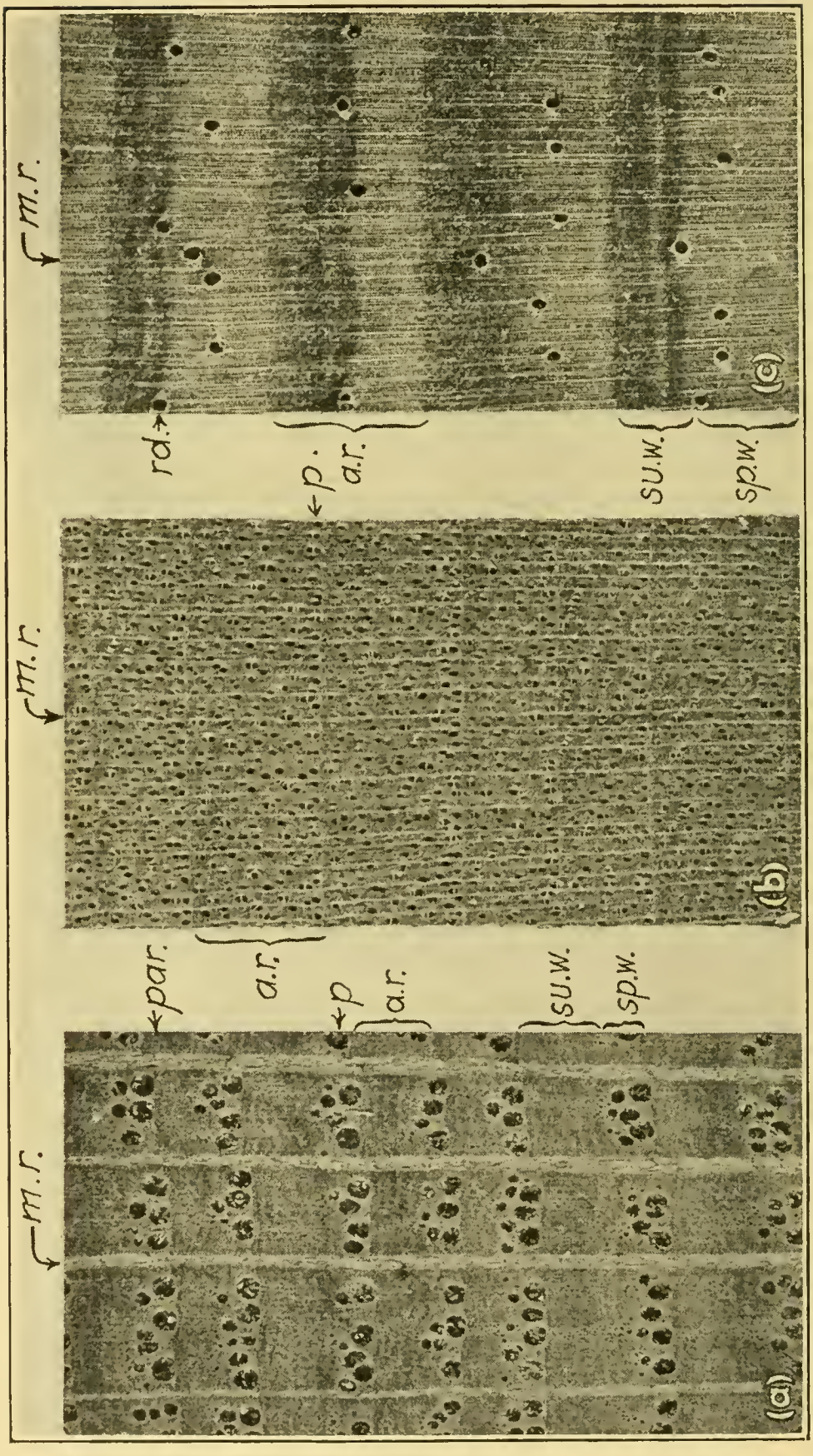


FIG. 5.—End surfaces of three types of wood magnified 7½ diameters: *a*, White oak (ring-porous); *b*, yellow birch (diffuse-porous); *c*, longleaf pine (non porous); *a.r.*, annual rings; *sp.w.*, springwood; *su.w.*, summerwood; *p.*, pores; *par.*, parenchyma; *r.d.*, resin duct; *m.r.*, medullary rays. (*Courtesy, Forest Products Laboratory.*)

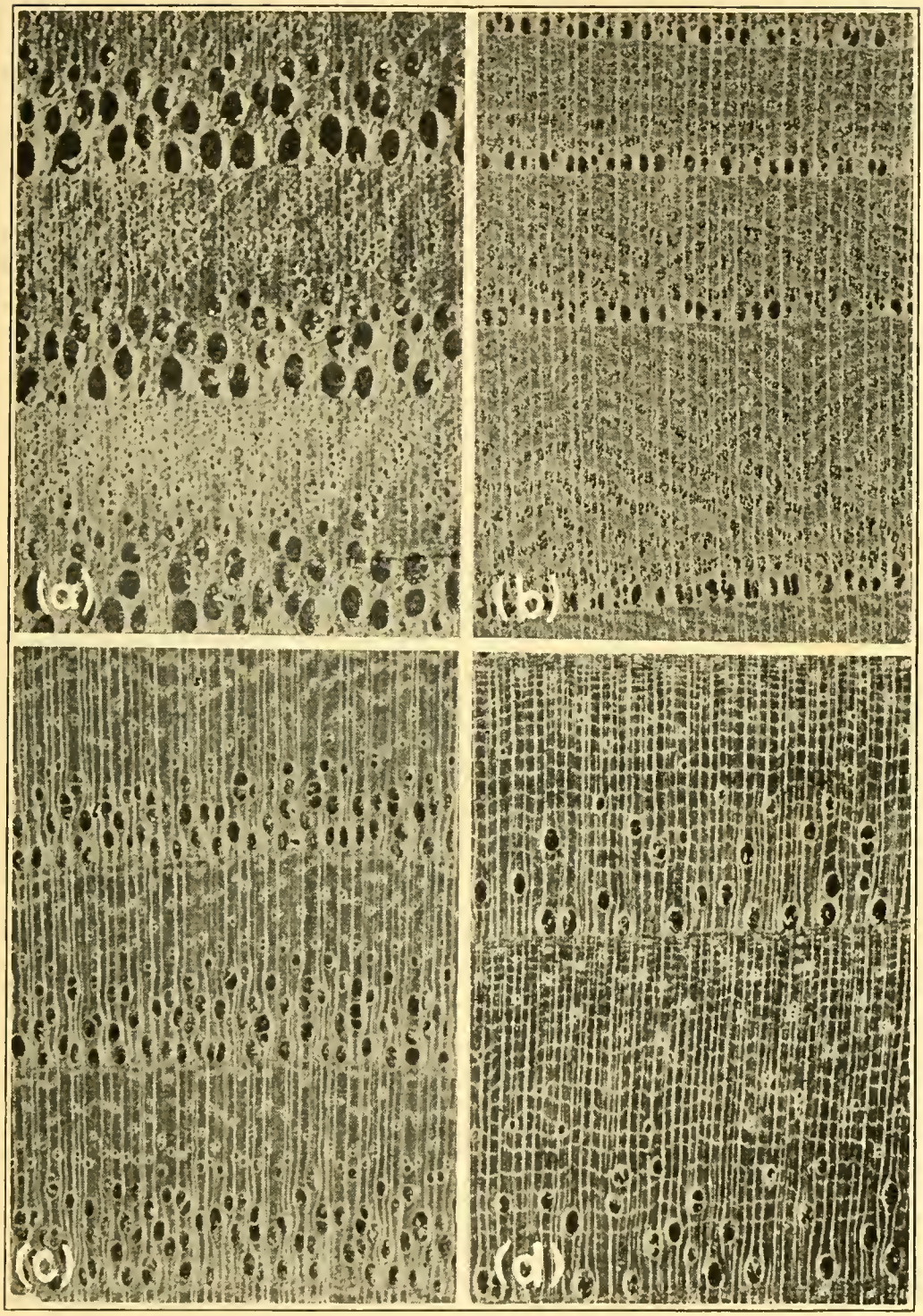


FIG. 6.—End surfaces of ring-porous woods magnified 7½ diameters. *a*, chestnut; *b*, white elm; *c*, white ash; *d*, pignut hickory. (*Courtesy, Forest Products Laboratory.*)

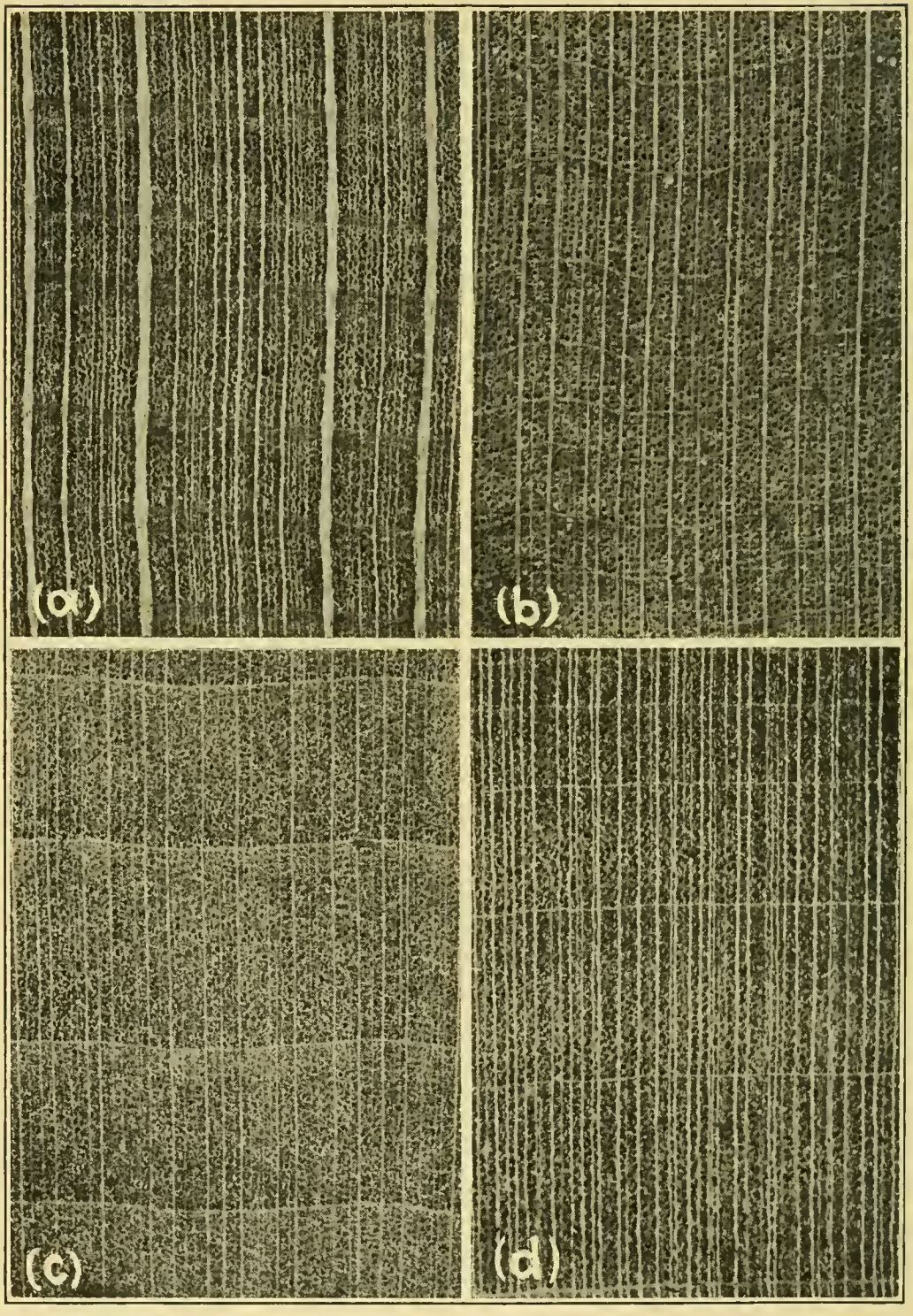


FIG. 7.—End surfaces of diffuse-porous woods magnified 7½ diameters. *a*, beech; *b*, sugar maple; *c*, basswood; *d*, yellow poplar. (*Courtesy, Forest Products Laboratory.*)

There also is considerable variation in the distribution of the pores. In most diffuse-porous woods they are scattered singly, or by twos or threes among the wood fibers. The smaller ones in ring-porous woods also may be scattered singly or by twos or threes, as in hickory and ash; they may be arranged in irregular radial rows usually more or less interrupted, as in oak and chestnut; they may be in concentric rows, in which case they usually form wavy bands, as in elm and hackberry; they may be in rounded groups of from three to fifteen or more, as in mulberry and coffeetree. See Figs. 5, 6, and 7 for some of these types of structures.

The size and arrangement of the pores are fairly uniform for each species and are excellent bases for the identification of woods.[1] The size and distribution of the pores also determine to a large extent the figure of the wood.

In certain hardwoods the pores in the heartwood and inner sapwood are more or less filled with ingrowths known as *tyloses*. Tyloses are abundant in the pores of the wood of the white oak group, mulberry, osage orange, black locust, catalpa, and are found to a lesser extent in many other species. The end view of the white oak in Fig. 5*a* shows tyloses in the pores. The pores in woods of the red oak group are not filled with tyloses as a rule; consequently, liquids pass through the woods readily making the red oaks unsuitable for tight cooperage unless the containers are sized on the inside with glue, paraffin, or other material. Tyloses hinder the penetration of preservatives into wood, but, fortunately, many woods that have tyloses are also highly durable without preservative treatment, although the tyloses in themselves do not make the wood durable.

5. Wood Parenchyma Cells.—These are comparatively short, thin-walled cells scattered among the fibers. Figure 3 shows the shape and relative size of typical wood parenchyma cells. They are so small that they usually cannot be seen individually even with a hand lens. Collectively they can be recognized on the smoothly cut end surface of hardwoods by the light-colored, or occasionally dark-colored tissue they form.

[1] For more information on the identification of woods see the following:

Record, S. J., "Identification of the Economic Woods of the United States." John Wiley and Sons, 2nd Ed., 1919.

Koehler, Arthur, "Guidebook for the Identification of Woods Used for Ties and Timbers." Miscellaneous Forestry *Bull.* 1917.

Wood parenchyma cells are arranged in numerous, distinct tangential lines in oak and hickory, and more obscurely so in persimmon, black walnut, butternut, beech, and basswood. In some woods the parenchyma cells surround the pores forming a light-colored ring or "halo" around them. Such an arrangement is found in oak and is characteristic of black ash and sassafras. In other woods the parenchyma may surround the pores and project sideways tangentially, often connecting pores somewhat separated. This arrangement is found in white ash, as is shown in Fig. 6*c*. In yellow poplar, cucumber, and magnolia the parenchyma cells are confined to a narrow layer, appearing as a line at the end of each year's growth. See end view of yellow poplar in Fig. 7*d*. In many woods the parenchyma cells are scattered here and there and cannot be seen without a compound microscope.

In the conifers, wood parenchyma cells are comparatively scarce. In woods in which they are present they often are filled with amber-colored resin which makes them readily visible under a lens as dark specks. In cypress and some of the cedars they often form dark zones.

The purpose of parenchyma cells is to store food materials whenever they occur in excess quantities in the tree.

6. Resin Ducts.—In pine, spruce, larch or tamarack, and Douglas fir there are special intercellular passages for storing and conducting resin. These are known as "resin ducts." They occur vertically at intervals among the tracheids and horizontally within certain medullary rays. Figure 5*c* shows resin ducts in yellow pine and Fig. 8*a* and *b* in white pine and Douglas fir.

On smoothly cut transverse surfaces, the resin ducts occasionally are visible to the unaided eye as minute holes, especially in the pines, but more often they appear as lighter- or darker-colored specks, and it is necessary to use a hand lens in order to see them distinctly.[1] On longitudinal surfaces, which have been exposed to the air for some time, the ducts appear as brownish lines running parallel with the fibers.

The exudation of resin from wood is a positive indication of the presence of resin ducts and never occurs in the normal wood of hemlock, cedar, cypress, redwood, and true fir.[2] Pitch pockets

[1] In examining the end surface of wood for resin ducts, parenchyma, pores, etc. it should first be cut smooth with a very sharp knife.

[2] Port Orford Cedar occasionally exudes oil which changes to a resin in contact with air. Exudations may also occur from wounded portions of redwood and hemlock.

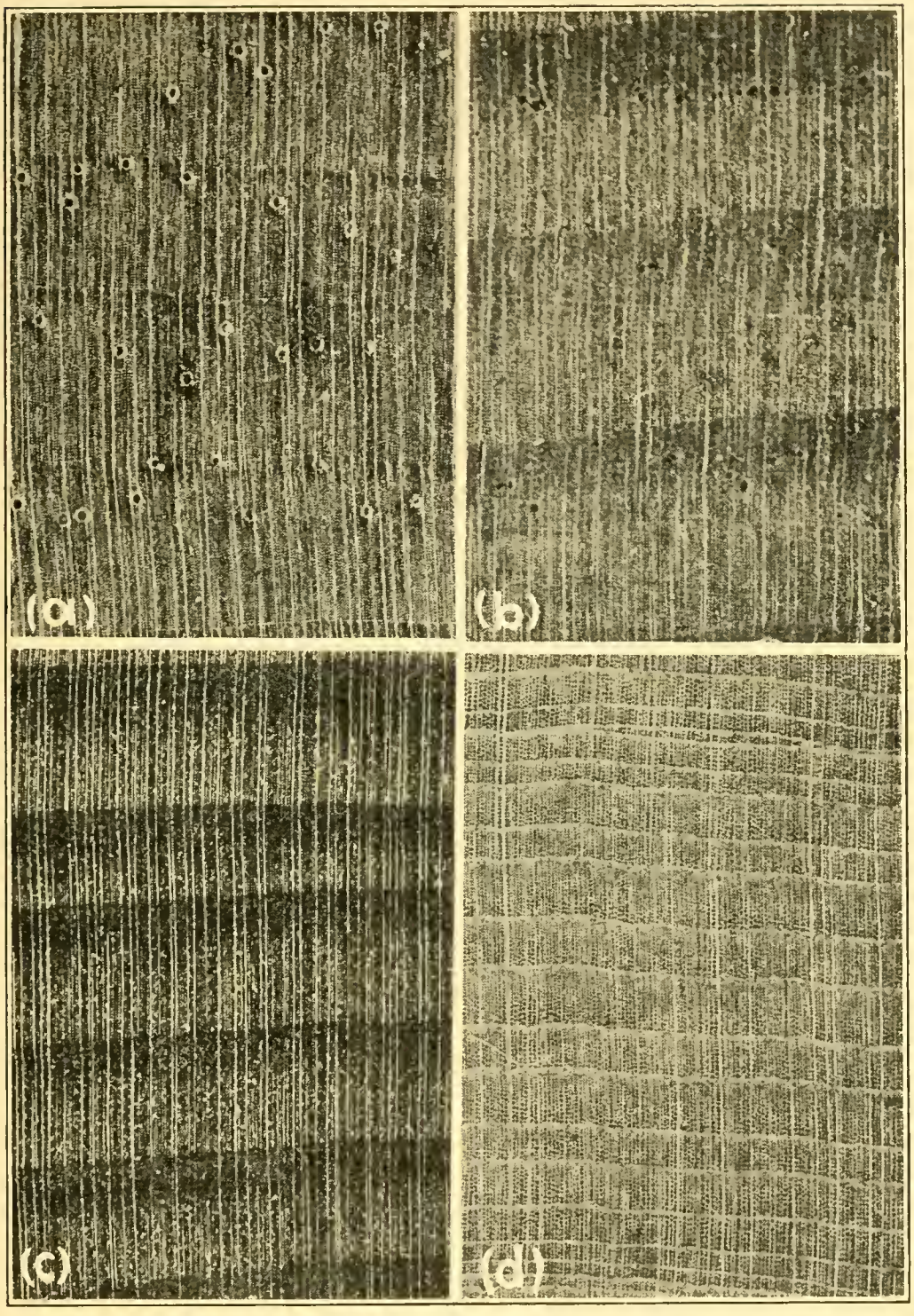


FIG. 8.—End surfaces of non-porous woods magnified 7½ diameters. *a*, eastern white pine; *b*, Douglas fir; *c*, western hemlock; *d*, redwood. (*Courtesy Forest Products Laboratory.*)

and pitch streaks also occur only in the species having resin ducts.

The resin ducts should not be confused with the pores of hardwoods which serve an entirely different purpose.

7. Medullary Rays.—In all woods, except the palms and yuccas, there are strips of cells (also parenchyma cells) running across the grain in a radial direction into the bark. These are known as *medullary rays* or simply *rays*. See Figs. 3, 4, and 5. Their purpose is to store food and to conduct sap from the bark to the

FIG. 9.—Cross-section of lodgepole pine showing annual rings. Note increase in width of rings after removing neighboring trees when this tree was 67 years of age. Four-fifths natural size. (*Courtesy, U. S. Forest Service.*)

sapwood, and vice versa. The ray cells and wood parenchyma cells are the only elements which contain protoplasm and are alive in the woody part of the stem, although other elements function in the life processes.

In our native woods the rays are largest in oak, in which they appear as distinct lines on the cross-section, and as "flakes" on the faces of radially cut lumber. In sycamore and beech they also are conspicuous but are much smaller than in the oak. In other woods they are still smaller, but they can be seen on split radial surfaces as fine strips running across the grain. Although they are very small in most woods they are very numerous. If the bark of a yellow pine log were removed and the ends of the

rays counted with the aid of a microscope, one would find about 15,000 per square inch.

The medullary rays play an important part in the drying, shrinking, and checking of wood. They also add beauty to some woods and are very helpful in identifying species.

8. Annual Rings.—In trees grown in a temperate climate the first wood cells produced in the spring of the year under the bark usually are larger than those produced later in the growing season, thus forming a sharp line of demarcation between the last cells formed in one year and the first ones formed the next spring and defining the well-known *annual rings*. See Figs. 5 and 9. False rings are formed when the activity of a tree has been retarded, before the end of the growing season, by drought, defoliation, insects, or other causes, and active growth is again resumed the same year after rains or the putting forth of new leaves, or the removal of whatever cause arrested the growth. False rings do not have a sharp outer limit but pass more or less gradually into the succeeding wood formed the same season.

Even under normal conditions the width of the annual rings varies from year to year because the conditions of growth are not always the same. Figure 9 shows the effect on the rate of growth of removing surrounding trees from a lodgepole pine which for 67 years had been competing with other trees for light, water, and nourishment.

Eccentric rings are produced in tree trunks which have the branches developed more on one side than on the other, in trunks of leaning trees, and in limbs and roots.

9. Springwood and Summerwood.—In many woods the cells formed in the spring are comparatively large and have thin walls, producing a light, soft, and weak layer known as the *springwood*. The cells formed later in the year are smaller and have thick walls, forming, on the outside of the springwood, a darker, harder, and stronger layer known as the *summerwood*, as shown in Fig. 5. Since summerwood is stronger than springwood, the percentage of summerwood determines to a large extent the strength of wood. This subject will be taken up more fully in Chap. V.

In some woods such as white pine, cedar, maple, birch, and the gums, the cells decrease in size only slightly toward the outer portion of each annual ring so that the distinction between springwood and summerwood is not clear. See the illustration of birch in Fig. 5.

In such woods, however, there is always enough difference in the size of the cells formed late in the season and those formed early the next spring so that there is a sharp line of demarcation for each year's growth. Tropical trees do not form well defined

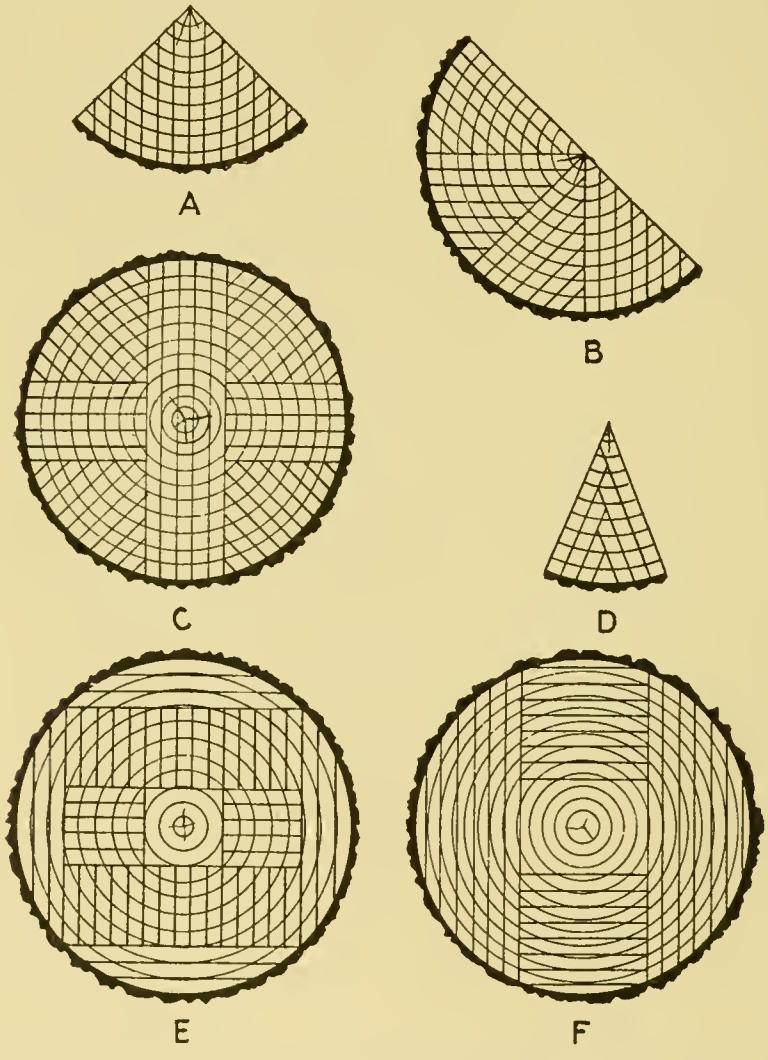


FIG. 10.—Diagrams illustrating methods of sawing logs. *A* to *D*, methods of quarter-sawing hardwoods; *A*, the original method and probably the one from which the term was derived; *D*, gives best quality of lumber but is not so commonly used as the other methods because the piece must be turned after each cut; *E*, method of cutting edge-grain flooring—the outer three boards in each quadrant are plain-sawed; *F*, common method of sawing plain-sawed lumber. The centers of *E* and *F* are "boxed heart" timbers.

annual rings, as a rule, although they may form zones of growth because of periodic climatic changes or other reasons.

10. Plain-sawed and Quarter-sawed Lumber.—Because of the presence of medullary rays and annual rings in wood it may be cut into lumber in two distinct ways: It may be cut more or less parallel with the rays, across the rings, that is, from the bark

toward the center, producing what is known as radially cut, quarter-sawed, edge-grain, vertical-grain, or rift-sawed lumber; or it may be cut more or less at right angles to the rays, or tangent to the rings, producing tangentially cut, plain-sawed, flat-grain, slash-grain, or bastard lumber. Figure 10 shows methods of sawing plain-sawed and quarter-sawed lumber.

For some purposes plain-sawed lumber is preferred and for other purposes quarter-sawed lumber. The following are the principal advantages of quarter-sawed or edge-grain lumber over plain-sawed or flat-grain lumber:

1. It shrinks less in width.
2. It twists and cups less.
3. In many woods, as in oak, sycamore, and mahogany, it gives a better figure.
4. It wears more evenly, and does not sliver so much.
5. It does not surface check or split open so badly in seasoning and, therefore, can be dried more rapidly in a kiln by giving it more severe treatment.

The following are the principal advantages of plain-sawed or flat-grain lumber:

1. It is cheaper to cut at the mill, and there is less waste in cutting.
2. In some woods, as in yellow pine, cypress, Douglas fir, and redwood, it gives a more beautiful figure.
3. It dries more rapidly than quarter-sawed lumber under the same conditions.
4. It does not collapse so easily in drying.
5. If knots are present, they are round instead of spike knots as in quarter-sawed boards.

11. Sapwood and Heartwood.—Logs of many species have an outer light-colored region, the *sapwood*, and an inner darker core, the *heartwood*. The cells in the sapwood function in the life processes of the tree by conducting sap and storing food. Only those cells which store food (parenchyma) are actually alive and contain protoplasm. The cells in the heartwood are all dead, and serve only to give strength to the tree.

As the inner sapwood changes to heartwood it becomes infiltrated with gums, resins, and other coloring matter, the exact nature of which is not fully known. These deposits usually make the wood darker and increase its resistance to decay.

In some woods there is little difference in the color of the heartwood and sapwood, for example, in spruce, hemlock, balsam fir, aspen, blue beech, beech, tupelo, cottonwood, basswood, holly, and hackberry. It cannot be said that such woods have no heartwood, for certain differences, such as moisture content, susceptibility to blue stain, durability, and ease with which liquids pass through, may exist between the inner and outer parts of the log.

The sapwood varies from ¼ to 6 or more inches in width, but it usually is 1 to 2 inches wide. It may contain only a few annual rings, as in black locust and osage orange, or over a hundred as in old pines. The following species have comparatively narrow sapwood, usually less than one inch in width: black locust, osage orange, mulberry, catalpa, sassafras, coffee tree, slippery elm, black ash, butternut, black cherry, western larch, northern white cedar, and western red cedar. In hickory, white ash, maple, dogwood, and persimmon the sapwood is so wide that it furnishes the bulk of the lumber cut from these species. In trees with large crowns, especially those that grow in the open, the sapwood is wider than in trees of the same species and same diameter with smaller crowns.

The sapwood usually is widest at the base of trees and decreases in width toward the top. The proportion of sapwood to heartwood, on the other hand, is usually greater in the top of the tree because in the top only a comparatively small amount of heartwood is present. On account of being on the outside of the heartwood, the sapwood comprises a larger proportion of the tree trunk than is often supposed. Tree trunks with wide sapwood may have less than 50 per cent heartwood when of merchantable size.

Occasional trees of western larch, Douglas fir, eastern red cedar, and western red cedar have zones of light-colored wood inside of the heartwood. These regions are more easily penetrated by creosote than the surrounding heartwood, in this respect resembling ordinary sapwood. The name "internal sapwood" has been applied to them. Figure 11 shows layers of internal sapwood in Douglas fir. In eastern red cedar and other junipers the heartwood is very irregular in outline, the sapwood often forming deep "bays" into the heartwood. Such streaks of sapwood add figure to the lumber when it is properly cut and finished.

Heartwood is generally more durable than sapwood when placed in positions subjecting it to decay, but in balsam fir, spruce, hemlock, aspen, and some other species there is little difference in the durability of the inner and outer parts of a log.

The dark color of heartwood often adds to the value of wood by giving it beauty, although for high-grade hickory and ash handles, maple flooring and furniture, and yellow pine interior finish the white sapwood is preferred on account of its light color. The

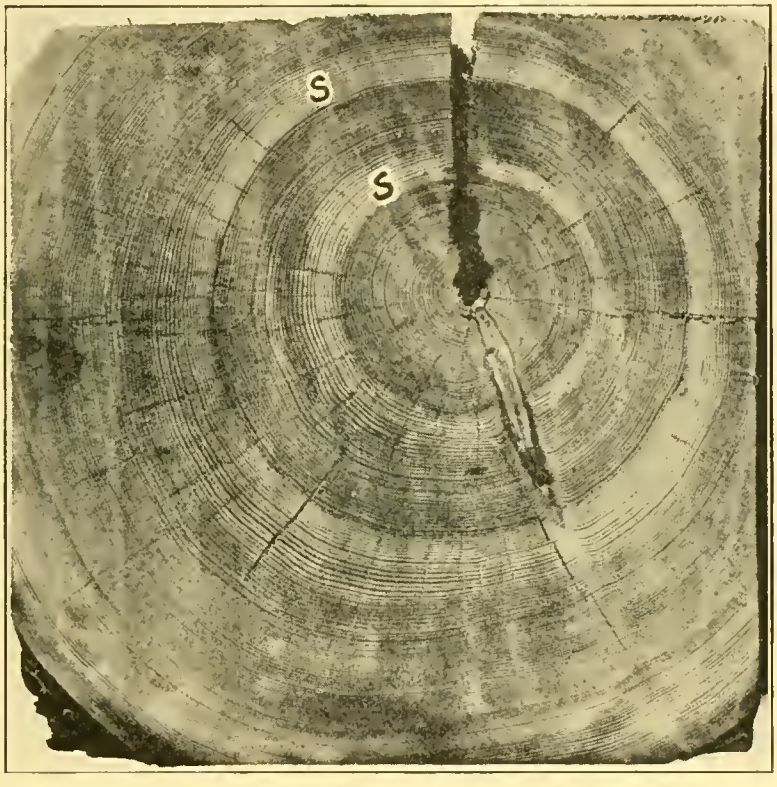


FIG. 11.—Layers of internal sapwood, *S*, in Douglas fir. (*Courtesy, Forest Products Laboratory.*)

sapwood also is preferred in the manufacture of shuttles from persimmon, and of spools from paper birch. Sapwood is freer from knots, shake, pitch streaks, and dote than heartwood.

It is a common belief that the sapwood of some species, especially ash and hickory, is stronger than the heartwood; while in other species, for example, pine and oak, heartwood is preferred where strength is essential. As will be explained more fully in Chap. V, sapwood is not necessarily stronger than heartwood, or *vice versa*. The strength depends on other factors, as density and freedom from defects.

In some woods which have a large amount of infiltrated matter in the pores or other cell cavities of the heartwood, as in ebony, rosewood, and pitchy softwoods, the heartwood may be noticeably heavier than the sapwood, but in most species there is no appreciable difference in the weight of sapwood and heartwood, except what is due to differences in growth or moisture content.

Sapwood allows the passage of liquids through it more readily than heartwood, and for this reason dries out more quickly and usually allows preservatives to enter more easily. These properties, however, make sapwood less desirable for tight cooperage. Coloring matter often leaches out of the heartwood when it is first soaked, but eventually the leaching ceases.

12. Grain and Texture.—The word "grain" is used rather loosely with respect to lumber, in fact some of the meanings are inconsistent. Woods with wide growth rings are often referred to as *coarse grained* and those with narrow rings as *fine grained.* If this meaning were strictly adhered to, tropical woods without definite growth rings could be neither coarse nor fine grained. Furthermore, a piece of basswood or maple with wide annual rings would be classed as coarse grained under this meaning, and a piece of oak with narrow rings would be classed as fine-grained lumber, yet most carpenters would not classify them as such. It is evident that when a yellow pine board with wide rings is called coarse-grained something more than the width of the rings is taken into consideration, for if the annual rings were composed entirely of soft springwood or hard summerwood the limits of the annual rings would be difficult to find, and the lumber would not be considered coarse grained. In practice, then, timber with *wide* and *conspicuous* annual rings (that is, rings in which there is considerable difference between springwood and summerwood) is classed as coarse grained.

The term coarse grained is also used in connection with woods with large pores, such as oak, chestnut, ash, walnut, and mahogany, irrespective of the width of the rings, although painters invariably classify them as *open-grained woods.* Accordingly, woods with small elements, such as gum, yellow poplar, and white pine, are classed as *fine-grained* or *close-grained.*

Even grain applies to lumber in which there is little contrast between springwood and summerwood, as in spruce, white pine, maple, birch, and mahogany. *Uneven grain* applies to lumber in which the summerwood is conspicuous and harder to work,

as in the hard pines, Douglas fir, tamarack, oak, elm, ash, and some others. The pattern maker prefers white pine to many other woods partly because of its even grain. Timber with annual rings of irregular width (common in cypress) is also said to have uneven grain, while timber in which the annual rings are fairly uniform in width is said to have even grain.

Some wood users prefer the word "texture" in place of grain when the size and distribution of the elements are referred to, as *coarse*

FIG. 12.—Spiral and straight-grained trunks of western yellow pines. Bear Valley, California. (*Courtesy, U. S. Forest Service.*)

or *fine texture, even* or *uneven texture.* Grain and texture are often used interchangeably.

Rough and *smooth* grain refer to the character of the surface of lumber after it is finished. Elm has a rougher grain than hickory or ash, and this is one reason why elm is not used extensively for tool handles, although the denser grades have the necessary toughness. Basswood has a smoother grain than cottonwood, although the two woods have about the same hardness. Whether wood is considered as rough- or smooth-grained depends in part on the size and direction of the wood elements and also in part on a certain tendency of the fibers to fray out from the surface, but remain partly attached, producing what is also known as *woolly grain.*

Another and entirely different use of the word "grain" is with respect to the direction in which the fibers extend.

Straight grain means that the fibers in tree trunks and timber products run practically parallel to the main axis.

Spiral grain means that the fibers in trees trunks take a spiral course giving the trunk a twisted appearance. This is illustrated in the tree trunk to the left in the foreground in Fig. 12. The twist may be either right handed or left handed, although right-handed twists seem to be more common. Wood with pronounced spiral grain is not so strong, in bending, as straight-grained material.

Spiral grain can be detected most easily in sawed material by splitting the wood in a radial direction. The cleft will follow the

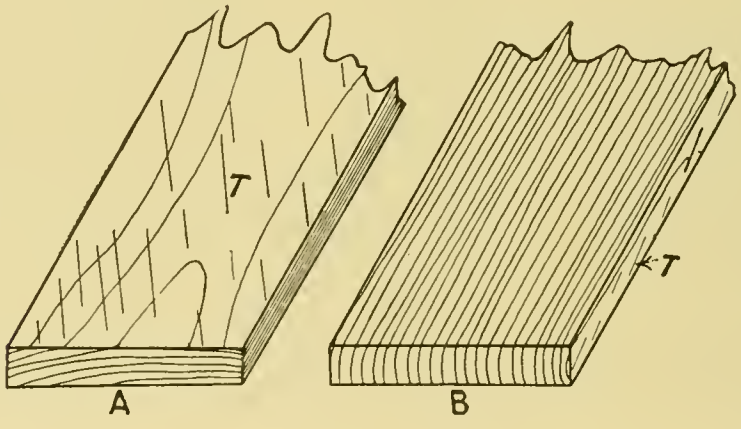


FIG. 13.—Showing spiral grain on the tangential faces, *T*, in *A*, a plain-sawed board, and in *B*, a quarter-sawed board.

grain, and the split surfaces will be twisted. This, of course, mutilates the piece and is not always permissible. Spiral grain can also be detected on the flat-grain faces by the direction of checks, pores, resin ducts, and medullary rays, since all these extend parallel with the fibers. The direction in which ink spreads on the longitudinal surface of wood also indicates the direction of the grain. The presence, but not the exact slope, of spiral grain can also be detected on the edge-grain faces by the inclination of the fibers pulled out by the planer. Figure 13 shows spiral grain in lumber.

Comparatively short straight-grained pieces can be cut out of spiral-grained trees by cutting parallel with the fibers. Logs are sometimes split, or "rived," in order to obtain straight-grained

material from them. This is done to some extent in making handles, staves, shakes, and airplane stock.

The slope of spiral grain varies considerably and may change with the age of the tree. In a tree inclined to be spirally grained, the slope usually increases from the center out, although exceptions occur. On some trees growing on exposed mountain sides the spiral has been found to run more nearly horizontally (like the thread of a screw) than vertically.

The cause of spiral grain has never been satisfactorily explained. Some believe it is due to the influence of prevailing winds on lopsided crowns, causing the trees to twist. There are two objections to this theory: In the first place, the trees are not actually twisted—it would take a tremendous force to twist a tree, and mechanical failure probably would occur; furthermore,

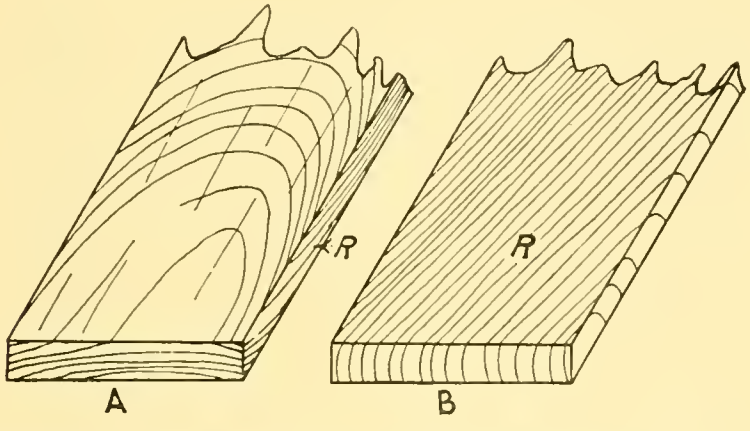


FIG. 14.—Showing diagonal grain on the radial faces, *R*, in *A*, a plain-sawed board, and in *B*, a quarter-sawed board.

the center would show the greatest twist because it would have been longest under this influence, yet neither of these evidences of twisting is found. In the second place, the spiral in some trees makes several complete revolutions, while if the above theory were correct the top would not twist more than 50 to 100 degrees from its original position. In spirally grained trees the fibers *grow* in an inclined position.

Diagonal grain is produced when straight-grained timber is not cut parallel with the fibers. The objections to it are the same as for spiral grain. It occurs in careless sawing, in sawing crooked logs, and in the common practice of sawing tapering logs parallel with the center instead of parallel with the bark.

If straight-grained timber is cut at a slant so that the grain slopes on the tangential faces, it has the superficial appearance of being spirally grained and should be classed as such.[1]

If the timber is cut so that the grain slopes on the radial faces, the direction of the grain usually shows up plainly because the annual layers of growth indicate the direction of the fibers. Diagonal grain of this kind may also be indicated on the tangential faces by the numerous parabolas formed by the annual rings. Figure 14 shows diagonal grain in lumber. The direction and slope of diagonal grain can also be determined by splitting a piece of wood tangentially, but this is not necessary except in woods with very indistinct annual rings.

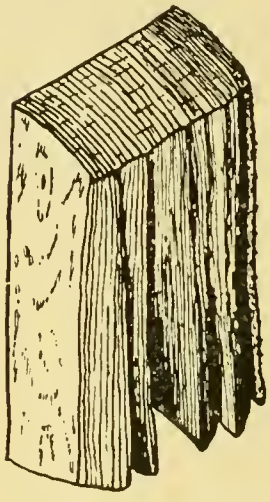


FIG. 15.—A block of wood split radially showing interlocked grain.

To avoid confusion it may be well to repeat that spiral grain may be determined by the slope of the fibers on the tangential faces as indicated by checks, etc., and diagonal grain by the slope of the fibers on the radial faces as indicated by the annual growth layers. Of the two, spiral grain is more difficult to detect and, therefore, more often overlooked. Both spiral and diagonal grain are often called *cross grain.*

Interlocked grain, also spoken of as cross grain, means adjacent layers of wood spirally inclined in opposite directions. These layers usually are between ½ and 2 inches thick. The gums, cottonwood, elm, sycamore, beech, and mahogany have characteristically interlocked grain, although it may occur in other woods, especially in butt logs. Interlocked grain does not weaken timber so much as plain spiral or diagonal grain, but it causes the lumber to twist in drying. Such wood is always difficult to split radially, although it may split fairly easily tangentially. Figure 15 illustrates the appearance of a piece of wood with interlocked grain split radially.

In quarter-sawed boards with interlocked grain the grain runs out in alternating layers on both sides, which makes it difficult to surface the lumber. When such lumber is properly surfaced,

[1] The only way to distinguish such slope of grain from true spiral grain is to split the piece radially. The split surfaces will be straight if the wood is cut from a straight-grained tree and twisted if cut from a spirally-grained tree.

these layers reflect the light differently giving the wood a "ribbon" or "stripe" effect as illustrated in Fig. 16.[1] In quarter-sawed veneer the "ribbons" which show the greatest cross grain or " short" grain shrink more along the length of the veneer than the adjacent ones and sometimes form checks across the "ribbon."

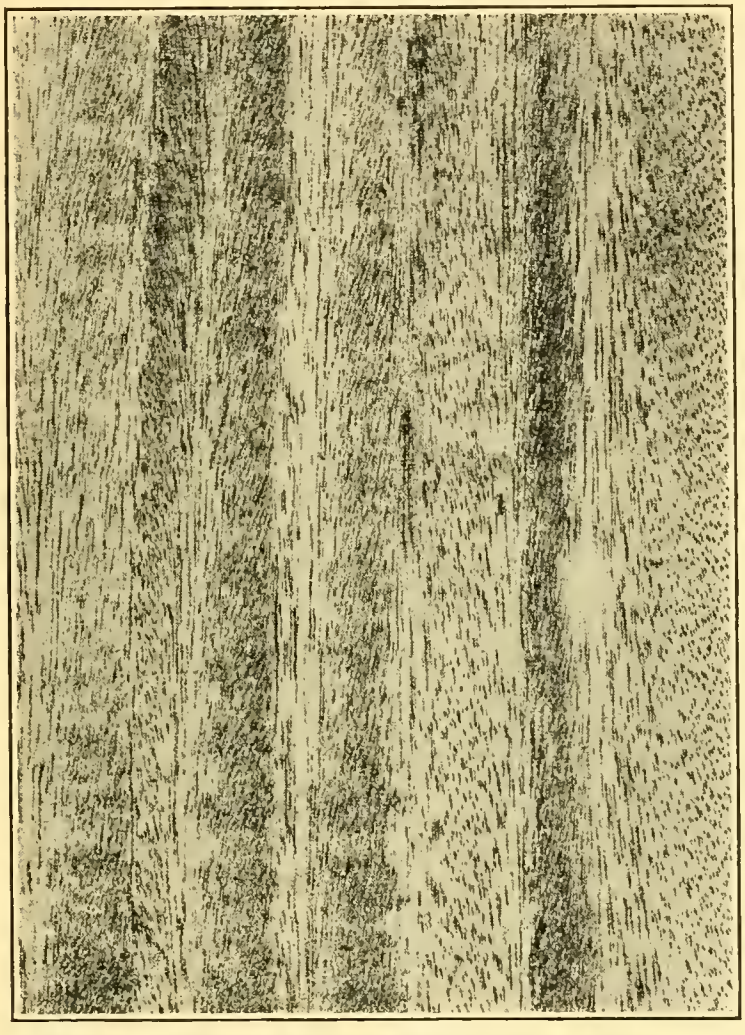


FIG. 16.—Ribbon or stripe figure in mahogany due to interlocked grain. (*Courtesy, Forest Products Laboratory.*)

Wavy grain is due to the wavy arrangement of the fibers and can be detected readily by splitting the wood radially, thereby producing a corrugated surface. Wavy-grained wood will split straight tangentially, but the wavy direction of the fibers may be seen on the tangential surface.[2] Therefore, to produce the best

[1] This is called "roe" or "roeyness" by some English writers.

[2] According to ROTH, some woods appear wavy or in transverse folds when split tangentially. Division of Forestry *Bull.* **10**, "Timber," p. 22.

effects in wavy-grained woods they should be cut radially. Figure 17 shows the appearance of wavy grain in a tropical wood. Wavy grain occurs in maple, birch, and redwood and occasionally in other woods. It occurs most commonly where the roots join the stem, or under large limbs because of the wrinkling of the fibers in these places. Fine wavy grain is also called "fiddle-back" grain.

FIG. 17.—Wavy grain in a tropical wood. Radial surface. (*Courtesy, Forest Products Laboratory.*)

Blister grain is produced by numerous irregular knoll-like elevations in the annual rings. It is conspicuous on the tangential surface, and, therefore, can be shown to best advantage on plain-sawed lumber and rotary veneer. It occurs in certain trees of yellow poplar, maple, mahogany, and southern pines and other species. Figure 18 shows this type of grain in yellow pine.

Curly grain is an irregular distortion of the fibers.

Landscape grain is a term applied to certain fantastically figured forms of curly grain.

Bird's-eye grain is caused by local sharp depressions in the annual rings. After these depressions are once formed, succeeding growth rings follow the same contour for many years. In

FIG. 18.—Blister grain in yellow pine. Tangential surface. (*Courtesy, Forest Products Laboratory.*)

plain-sawed lumber and rotary veneer these conical depressions are cut through crosswise and show a series of circlets, portions of the annual rings, suggesting rather remotely a bird's eye. Figure 19 shows bird's-eye grain in maple, in which it is quite common. Lodgepole pine and to a less extent western yellow pine, spruce, and larch lumber also show numerous slight depres-

sions on the tangential surface, somewhat resembling the bird's-eye grain of maple.

Silver grain is the name given to the flakes, or medullary rays, seen on radial surfaces. It gives quarter-sawed oak and sycamore their chief beauty.

FIG. 19.—Bird's-eye maple. (*Courtesy, Forest Products Laboratory.*)

13. Burls.—Burls are produced by a local development of numerous dormant buds brought about, according to Boulger,[1] by injury from insects or mechanical means. The burls on black ash, cherry, maple, walnut, and redwood are highly prized by cabinet and novelty makers. Figure 20 shows a portion of a cherry burl.

[1] "WOOD: A Manual of the Natural History and Industrial Application of Timbers of Commerce." Longmans, Green and Co., New York, 1908.

14. Figure.—Figure in wood is the pattern produced by the annual rings, medullary rays, distortion of fibers, and irregular infiltrations of coloring matter. It is often used with the same meaning as grain. The figure formed by the annual rings is most pronounced in woods with a marked contrast between springwood and summerwood as oak, ash, and yellow pine.

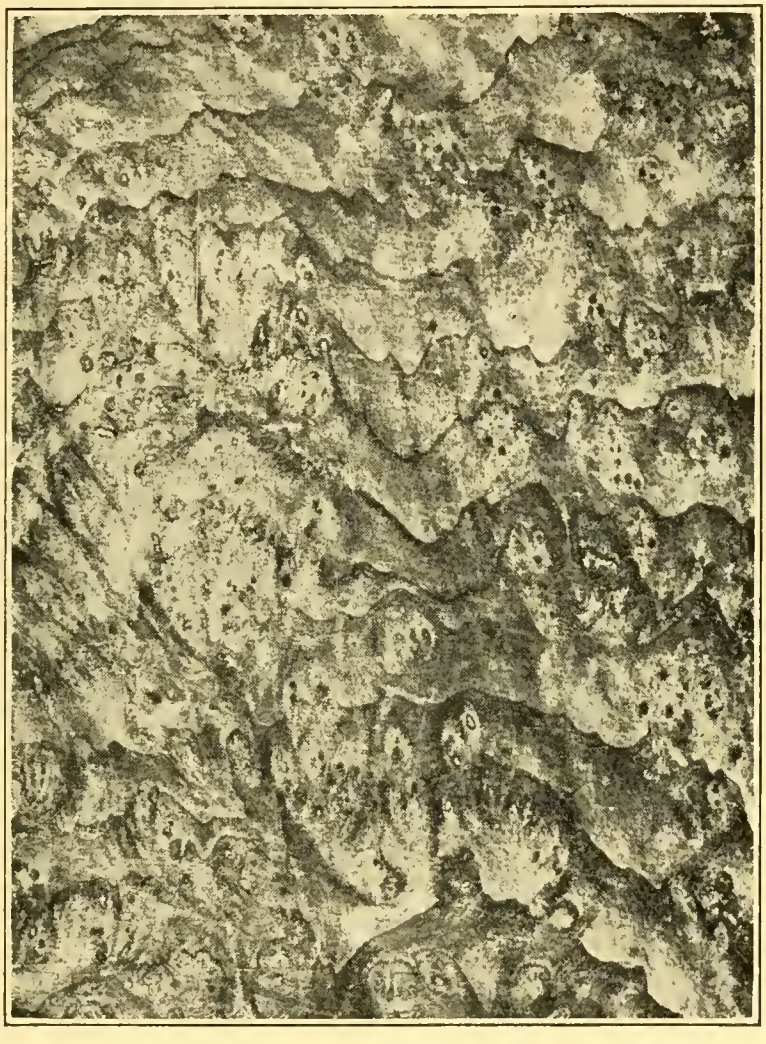


FIG. 20.—Cherry burl. (*Courtesy, Forest Products Laboratory.*)

In such woods the figure appears to best advantage in plain-sawed lumber. It can be made more prominent by the use of fillers, stains, or by carefully burning and brushing out the soft springwood as in "sugi"[1] cypress. Quartered oak veneer which is cut so that the medullary rays seem to run at an angle with the

[1] Sugi is the name of a Japanese wood (*Cryptomeria japonica*) which is considered particularly decorative when eroded by long exposure to the waves of the sea, as in driftwood.

fibers sometimes is matched so that the angle of the rays in adjacent pieces is reversed, in this way producing a herring-bone figure.

Whenever the fibers do not run parallel to each other as in interlocked, wavy, and curly-grained woods the reflection of light, which changes with the angle of vision, produces an attractive figure.

Sections through a crotch or from the stumps of rare woods have an extra market value because of the irregular figures produced by the distorted grain in these parts of the tree.

In Circassian walnut and some red gum, irregular darker streaks occur in the heartwood without any conformity to the annual rings. These streaks are largely responsible for the figure of these woods and can be seen equally well on radial and tangential surfaces.

15. Knots.—Knots are the bases of limbs and usually originate at the center of the tree, although knots due to sprouts and suckers originate at some distance from the pith. Knots usually slope upward so that the wood elements pass with a gradual curve from the trunk into the lower part of the branch, thus allowing an uninterrupted flow of sap from the roots to the leaves. The fibers in the wood above the knot have a less direct connection with the branch. For this reason it is much easier to split around a knot by applying the ax to the wood above the knot. If wood is split from immediately below a knot, the cleft will invariably run into the knot.

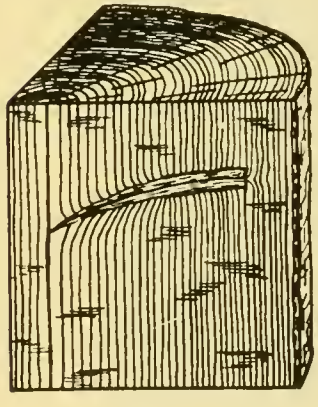


FIG. 21.—A block of wood cut radially showing knot and how it heals over after limb breaks off.

Most of the lower limbs of trees die in the course of time because of the dense shade cast by those above. Such dead limbs have no connection with the wood formed in the trunk after their death. Consequently, "dead" knots in lumber often are loose and fall out, while "live" knots have a firm connection with the surrounding wood. Dead branches are ultimately weakened by decay and break off. The stub or knot left in the tree heals over, and succeeding growth produces clear lumber (Fig. 21). Trees grown in the forest produce more clear lumber than trees grown in the open on which the lower branches persist for a longer time.

CHAPTER II

THE PHYSICAL PROPERTIES OF WOOD

The physical properties of a substance are those which are manifested without any chemical change taking place, as weight, hardness, color, absorption of moisture,[1] etc. For convenience, those properties which can be determined only by applying an outside force to wood, such as breaking strength, elasticity, and hardness, are described separately under the head of "Mechanical Properties" in Chap. IV.

16. The Weight of Wood.—The weight of the wood used in the manufacture of certain articles is important. For example, for mallets, ball bats, and bowling balls a heavy wood is essential, and for life preservers, floats, tent poles, and canoes a light wood is desirable. Usually, however, the weight of wood is considered of secondary importance in its utilization, the strength, beauty, workability, and durability being the controlling factors in its selection.

Indirectly, however, the weight of wood plays an important part in its utilization because it influences the cost of handling and transportation. Furthermore, the dry weight indicates the strength, shrinkage, and some of the other properties of wood.

The weight of wood depends upon: (1) Its density, that is, the actual amount of cell wall; (2) the amount of mineral matter or ash; (3) the resin, or pitch, and other non-mineral substances which are not part of the cell wall; and (4) the moisture in the wood. The first and last factors, that is, the amount of cell wall and the moisture content, show the greatest variation. The ash in wood forms a very small proportion of its total weight (usually 1 to 2 per cent) and is negligible as far as shipping weights and the handling of lumber are concerned. Occasionally pieces of pine and Douglas fir contain enough resin to increase their weight appreciably. Such pieces are known as "lightwood" (because they burn readily) and may contain resin to the amount of

[1] Change in moisture content of wood may be accompanied by chemical changes, but in this text it will be considered as a purely physical phenomenon.

one-third of their weight. Ordinarily the resin content of the pines constitutes 2 to 9 per cent of the dry weight, and of Douglas fir about 1 per cent. Other substances, such as tannin, oils, gums, sugars, and starch, occur only in very small quantities, and do not add appreciably to the weight except in the heartwood of some tropical woods, for example, ebony and rosewood, in which the cells are almost completely filled with gum and other substances.

The weight of absolutely dry wood varies between wide limits, depending upon the amount of air space (cell cavities) present in the wood. If dry wood could be compressed so that all the cells were flattened and their cavities closed up and no air left in the wood, it would weigh practically the same per cubic foot for all species except woods which contain considerable resin or other infiltrated matter. Cottonwood would weigh as much as oak, and cedar as much as tamarack. In fact the material of which the cell walls are composed is practically the same in all woods. It weighs 1.54 times as much as an equal amount of water. Thus a cubic foot of solid wood substance would weigh 96 pounds. It is the cell cavities or pores in wood that make it lighter and cause most species to float. A very thin section of wood or fine sawdust will sink immediately, when placed in water, and larger pieces can be made to sink in a short time by boiling them, which drives out most of the air and allows water to enter. When timber becomes water-logged, the air is gradually replaced by water. Some woods have such small cavities in the cells in proportion to the amount of wood substance that the air in them is not sufficient to keep them afloat even when they are perfectly dry. Lignum-vitae and ebony are examples of such woods.

The weight of wood is expressed in several ways. It may be stated in pounds per thousand feet board measure, in which case the amount of seasoning and actual dimensions of the lumber must be taken into consideration. When greater accuracy is desired, the weight usually is expressed in pounds per cubic foot or as specific gravity, and the moisture content definitely stated.

Table I shows the weight of rough lumber, logs, and cordwood of common hardwoods, both green and air dry. In Table II all the important woods are classified as to weight.

17. Meaning and Determination of Specific Gravity.—By specific gravity is meant the ratio of the weight of an object to that of an equal volume of pure water at 4° C. Except for very

exacting work, however, the temperature of the water need not be considered. If a piece of wood has a specific gravity of 0.42, it means that it is forty-two hundredths times as heavy as an equal volume of water. Since the weight of a cubic foot of water is very nearly 62.5 pounds, a wood with a specific gravity of 0.42 weighs 26¼ pounds per cubic foot. When the metric system is used, the specific gravity may be obtained directly by dividing the weight of the specimen in grams[1] by the volume of the speci-

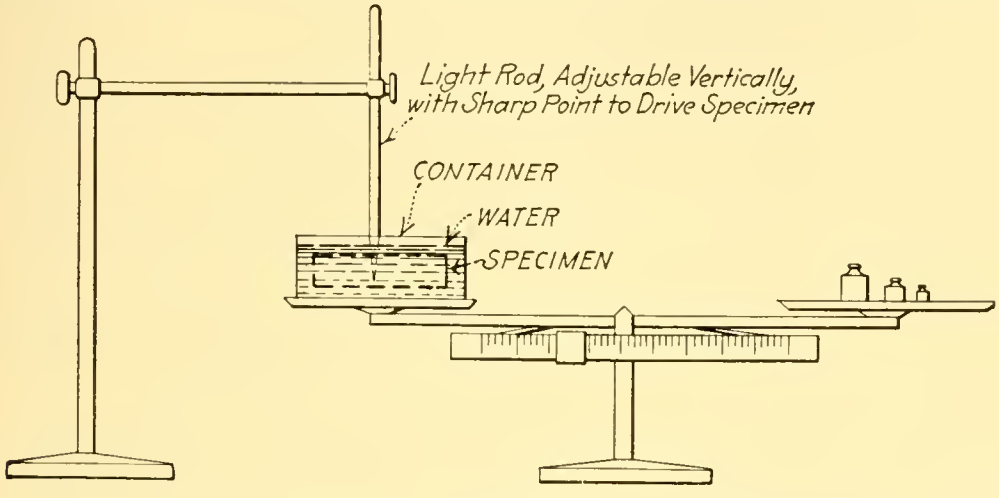


FIG. 22.—Method of determining volume of wood by weighing amount of water displaced.

men measured in cubic centimeters because a cubic centimeter of water at 4° C. weighs 1 gram. For pieces of irregular shape, or when great accuracy is desired, the specific gravity may be obtained as follows: Weigh the piece of wood. Next weigh a pan partly filled with water, then without removing it or the weights from the balance, completely submerge the specimen in the water by means of a sharply pointed stout wire held rigidly so that the wood does not touch the pan, as illustrated in Fig. 22. Quickly add weights till the scales again balance. The weight of the wood is grams, or other units, divided by the added weight in the same units gives the specific gravity. For example, if a piece of wood weighs 240 grams and it takes 800 grams to balance the scales after the wood is submerged, the specific gravity of the wood is $\frac{240}{800}$ or 0.30.

[1] If measurements are made in inches and pounds or ounces, find the weight in pounds per cubic foot and divide by 62.5 for specific gravity, or use the following reduction factors: 1 cubic inch = 16.4 cubic centimeters, 1 ounce = 28.4 grams, and 1 pound equals 454.0 grams.

TABLE I.—APPROXIMATE WEIGHTS OF VARIOUS WOOD PRODUCTS[a]

Species	Lumber (per 1,000 board feet)			Logs (per 1,000 board feet log scale, Doyle rule)[b]						Cordwood, bolts, butts, etc., per cord[b]	
	Green, pounds	Air-dry, pounds	Rough (classed as 1-inch thick) "shipping dry," pounds	12 inches diameter[c]		18 inches diameter[c]		24 inches diameter[c]			
				Green, pounds	Dry, pounds	Green, pounds	Dry, pounds	Green, pounds	Dry, pounds	Green, pounds	Dry, pounds
Ash, white	4,000	3,500	[d]3,800	11,100	9,700	7,700	6,800	6,600	5,700	4,300	3,800
Aspen (popple)	3,900	[e]2,200	2,250	10,800	6,200	7,600	4,300	6,400	3,700	4,200	2,400
Basswood	3,400	2,100	[d]2,500	9,500	5,900	6,600	4,100	5,600	3,500	3,700	2,300
Beech	4,600	3,600	[d]4,000	12,700	10,100	8,900	7,000	7,500	6,000	5,000	3,900
Birch, yellow	4,800	3,700	[d]4,000	13,200	10,300	9,200	7,200	7,800	6,100	5,100	4,000
Cedar, western red	2,200	1,900	[f]3,000	6,200	5,300	4,300	3,700	3,700	3,100	2,400	2,100
Cherry, black	3,800	3,000	[d]3,800	10,500	8,300	7,300	5,800	6,200	4,900	4,100	3,200
Chestnut	4,600	2,500	[d]2,800	12,600	7,000	8,800	4,900	7,500	4,100	4,900	2,700
Cottonwood	3,600	2,200	[d]2,800	10,700	6,300	7,500	4,400	6,300	3,700	4,200	2,500
Cypress, southern	4,200	2,800	[d]3,000	11,800	7,800	8,200	5,500	7,000	4,600	4,600	3,100
Elm, white	4,000	2,900	[d]3,100	11,300	7,800	7,900	5,500	6,700	4,600	4,400	3,100
Slippery	4,600	3,300	[d]4,000	12,600	9,200	8,800	6,400	7,400	5,500	4,900	3,600
Fir, balsam	3,700	2,100	.....	10,400	5,800	7,200	4,000	6,100	3,400	4,000	2,200
Douglas	3,100	2,800	[f]3,300	8,700	7,700	6,100	5,400	5,200	4,600	3,400	3,000
Gum, black	3,700	3,000	[d]2,800	10,400	8,300	7,200	5,800	6,100	4,900	4,000	3,200
Red (sweet)	3,900	2,800	[d]3,300	10,600	8,100	7,400	5,600	6,300	4,800	4,200	3,100
Hackberry	4,400	3,500	[d]3,200	11,300	8,900	7,900	6,200	6,700	5,200	4,400	3,500
Hemlock (eastern)	4,000	2,400	[g]2,500	11,200	6,600	7,800	4,600	6,600	3,900	4,400	2,600
Hickory	5,200	4,300	[d]4,500	14,700	11,900	10,300	8,300	8,700	7,000	5,700	4,600
Juniper (western)	.....	.....	.....	.....	.....	.....	.....	.....	.....	4,000	3,200
Locust, black	4,800	4,100	.....	13,400	11,300	9,300	7,900	7,900	6,700	5,200	4,400
Maple, sugar	4,700	3,600	[d]3,900	12,900	10,000	9,000	7,000	7,600	5,900	5,000	3,900

Red	4,300	3,000	[d]3,300	11,900	8,200	8,300	5,700	7,100	4,900	4,700	3,200
Silver	3,800	2,800	[d]3,300	10,500	7,800	7,300	5,400	6,200	4,600	4,100	3,000
Oak, red	5,400	3,600	[d]4,000	14,800	10,400	10,300	7,300	8,800	6,200	5,800	3,900
White	5,200	4,000	[d]4,000	14,400	10,900	10,000	7,600	8,500	6,500	5,600	4,300
Pine, jack	4,200	2,500	.....	11,500	6,900	8,000	4,800	6,800	4,100	4,500	2,700
Loblolly	4,500	3,200	.....	12,400	9,000	8,700	6,300	7,400	5,300	4,300	3,200
Longleaf	4,000	3,500	[h]3,500	11,100	9,700	7,700	6,800	6,500	5,700	4,000	3,500
Norway (red)	3,500	2,800	.....	9,700	7,800	6,800	5,500	5,700	4,600	3,500	2,800
Piñon	.....	.....	.....	.....	.....	.....	.....	.....	.....	3,900	3,000
Pitch	4,500	3,000	.....	12,400	8,300	8,700	5,800	7,400	4,900	4,900	3,200
Shortleaf	3,700	3,000	[h]3,300	10,400	8,300	7,200	5,800	6,100	4,900	4,000	3,200
Slash	4,400	3,700	.....	12,200	10,400	8,500	7,200	7,200	6,100	4,800	4,000
Sugar	4,200	2,200	.....	11,500	6,200	8,000	4,300	6,800	3,700	4,500	2,400
Western yellow	4,100	2,300	[i]2,600	11,300	6,500	7,900	4,500	6,700	3,800	4,400	2,500
White	3,200	2,200	[g]2,400	9,000	6,200	6,300	4,300	5,300	3,700	3,500	2,700
Poplar, yellow (tulip)	3,200	2,400	[d]2,800	8,800	6,500	6,100	4,500	5,200	3,800	3,400	2,500
Redwood	3,200	2,100	[j]2,100	8,900	5,900	6,200	4,100	5,200	3,500	3,500	2,300
Spruce, eastern	2,800	2,400	.....	7,700	6,600	5,400	4,600	4,600	3,900	3,000	2,600
Sycamore	4,300	3,000	[d]3,000	12,000	8,300	8,400	5,800	7,100	4,900	4,700	3,200
Tupelo gum (bay poplar)	5,500	3,000	[d]2,800	15,200	8,500	10,600	5,900	9,000	5,000	5,900	3,300
Walnut, black	4,300	3,000	[d]3,800	11,900	8,200	8,300	5,700	7,100	4,900	4,700	3,200
Willow	4,300	2,100	[d]2,800	11,800	6,000	8,200	4,200	7,000	3,500	4,600	2,300

[a] These weights are not the shipping weights prescribed by any railroad or any State railroad commission. The weights here given for "green" lumber are based largely upon the weights of wood cut and shipped in the log for varying distances to the Forest Products Laboratory, Madison, Wis., for purposes of testing. The "green" weights for lumber are, thus, not the weights of the wood when cut. There is no recognized standard green weight for wood. This table is taken from United States Department of Agriculture *Farmers' Bull.* **1210,** "Measuring and Marketing Farm Timbers."

[b] Weights of logs and cordwood computed from A. K. Armstrong's weights of hardwood per cubic foot (90 cubic feet per cord).

[c] Diameter inside bark at small end.

[d] Weights of rough lumber are official standard weights of the National Hardwood Lumber Association, unless otherwise indicated.

[e] Lumberman's Bureau.

[f] West Coast Lumberman's Association.

[g] *Eng. News*, vol. 63, No. 18.

[h] Southern Pine Association. [i] Western Pine Manufacturers' Association. [j] California Redwood Association.

If dry wood is used, it must be made non-absorptive by warming it and dipping it in hot paraffin while still warm. After the block has cooled, all superfluous paraffin should be scraped off. For many purposes it is more desirable to determine the volume of the wood, when fully saturated, since in this condition it may be submerged without coating it with paraffin. Furthermore, it will have reached an extreme condition which can easily be duplicated; while, if shrinkage has taken place, the results are more variable since wood shrinks differently with different methods of drying. The oven-dry weight[1] is preferred since it also represents an extreme condition which can easily be duplicated. Both volume and weight, however, may be determined at any moisture content.

It must be remembered then that in speaking of the weight per cubic foot or the specific gravity of wood it should be stated whether the volume of the wood was measured when the wood was green or after shrinkage began, and whether the weight was determined when oven dry, partly seasoned, or green.

18. Variation in Weight of Wood.—The various species of wood differ greatly from one another in weight as is shown in Table II. Even in the same species the dry weight of the wood is not always the same but varies within certain limits, depending upon its density. Some species vary a great deal in weight. Pieces of cypress and tupelo gum lighter than cork may be found, while others are as heavy as yellow pine. Some pieces of mahogany are twice as heavy as others of the same size. Usually the variation in a species is less.

Within the same tree certain variations in weight occur. In general, the bases of limbs (knots) contain the heaviest wood, especially in conifers, next the butt logs, then the top logs, and lastly the roots. This statement does not hold for trees with swelled butts, growing in the southern swamps, such as ash, cypress, and tupelo. In such trees the lightest wood in the trunk is found at the base, although the roots are still lighter. Because of their lightness tupelo gum roots are sometimes used in making floats for fish nets.

In a cross-section of mature trees the outer portion often is lighter than the portion nearer the center. In conifers the wood

[1] Wood dried at 212° F. until it ceases to lose in weight is said to be oven-dry, although it takes a temperature of from 220 to 225° F. to drive off all hygroscopic moisture.

TABLE II.—THE MORE IMPORTANT SPECIES OF WOOD CLASSIFIED ACCORDING TO WEIGHT

Species[a]	Pounds per cubic foot at 12 to 15 per cent moisture[b]	Specific gravity oven-dry based on green volume	Estimated shipping weight in pounds per 1,000 board feet of rough lumber 1 inch or more in thickness[c]
Very light: Northern white cedar.	18 to 22	.25 to .30	2,100 to 2,300
Light: Western red cedar, Engelmann spruce, red fir, basswood, yellow buckeye, incense cedar, balsam fir, Sitka spruce, black willow, white fir, noble fir, butternut.	22 to 27	.30 to .36	2,300 to 2,600
Moderately light: Sugar pine, aspen, white spruce, white pine, grand fir, yellow poplar, cottonwood, red spruce, lodgepole pine, western yellow pine, eastern hemlock, western white pine, jack pine, chestnut, western hemlock, Douglas fir (Mountain type), redwood, Port Orford cedar, bald cypress.	27 to 32	.36 to .42	2,600 to 3,000
Moderately heavy: Sassafras, white elm, silver maple, cucumber, Norway pine, red gum, tupelo gum, Douglas fir (Pacific Coast type), sycamore, black ash, evergreen magnolia, black gum, pitch pine, black cherry, paper birch, western larch, red maple, slippery elm, hackberry, tamarack, shortleaf pine.	32 to 39	.42 to .50	3,000 to 3,500
Heavy: Holly, loblolly pine, black walnut, white ash, beech, yellow birch, longleaf pine, sugar maple, commercial red oaks, rock elm, honey locust, slash pine, sweet birch, commercial white oaks.	39 to 49	.50 to .60	3,500 to 4,100
Very heavy: Pecan hickories, hornbeam, dogwood, persimmon, true hickories, black locust.	49 to 61	.60 to .72	4,100 to 4,800

[a] Arranged in each group approximately in the order of increasing weight. Individual weights of these and other species will be given in Table X, page 82.

[b] The average weight of a cubic foot of kiln dried wood at 8 per cent moisture is 1 to 2 pounds less than that of the same species air dried.

[c] Wood considered air dry, but moisture content may vary considerably.

within 1 or 2 inches of the center often is lighter than that further from the center. Numerous exceptions occur, however, so no definite statements can be made along these lines.

19. Moisture in Wood.—The moisture in green wood is often referred to as "sap." It is not pure water but contains in solution small quantities of mineral matter brought up from the soil and organic matter manufactured in the tree.

Moisture is contained in wood in two ways: (1) That which is in the cell cavities, like honey in a comb; and (2) that which is absorbed by the cell walls.

When wood dries, the moisture first leaves the cell cavities and when these are empty the cell walls begin to dry out. The condition in which the cell cavities are empty but the cell walls are fully saturated is known as the *fiber-saturation point.* Wood does not begin to shrink or increase in strength in drying until this point is reached.

The amount of moisture in wood is important in its utilization, since it affects its weight, strength, shrinking or swelling, durability, finishing, conductivity of heat and electricity, inflammability, and permeability by liquids.

20. Determination of Moisture Content.—The moisture content of wood usually is expressed in per cent of the oven-dry weight. Forty per cent moisture based on the oven-dry weight means that the water in the wood weighs 40 per cent as much as the dry wood. This method of expressing moisture content is more satisfactory than basing the percentage on the total weight of the wood and moisture, since the total weight changes with each change in moisture while the dry weight is constant. Either method is correct however, but it should always be stated on what the moisture per cent is based.

The per cent of moisture in wood is determined as follows: A section, measuring not more than 1 inch with the grain, is cut out across the piece at least 2 feet from the end, unless the whole piece is less than 4 feet long, in which case the section is cut out of the middle. All loose slivers are trimmed off and the section carefully weighed (preferably in grams) to an accuracy of $\frac{1}{10}$ of 1 per cent. The section is then placed in an oven heated approximately to 212° F. If an oven is not available, the section may be dried on live steam pipes, although this method may give less accurate results. When the section has attained a constant weight, it is considered oven-dry. The total loss in weight

represents the amount of moisture in the wood unless it contained volatile oils. Dividing the amount lost by the dry weight and multiplying by 100 gives the per cent of moisture based on the oven-dry weight.

For example, if a piece of wood weighs 288 grams before drying in the oven, and 192 grams when dry, its moisture content is computed as follows: $288 - 192 = 96$; $96 \div 192 \times 100 = 50$ per cent moisture based on the oven-dry weight. Based on the original weight it would be, $96 \div 288 \times 100 = 33\frac{1}{3}$ per cent.

21. Variation in Moisture Content.—In green trees the sapwood often contains considerably more water than the heartwood, but in some conifers and many hardwoods the moisture distribution is more uniform.

Whether the upper part or butt of a tree contains more moisture per unit volume depends upon the species and conditions under which the tree grew. Trees in which the moisture is confined mostly to the sapwood may contain more water in proportion to their volume in the top logs because these are composed largely of sapwood. On the other hand, trees in which the moisture distribution is more uniform contain more water in the butt logs as a rule. Butt logs of sugar pine, western larch, redwood, and western red cedar often sink in water, although the upper logs float.

It is a common belief that trees contain more moisture during the growing season, when the sap is said to be "up," than in the fall and winter when the sap is said to be "down." This belief has no foundation in fact. Tests made in the United States and Europe show that trees cut in the winter have fully as much water in them as trees cut in the summer. Furthermore, if the sap went down in the fall, logs cut in the winter would be lighter than those cut in the summer, yet such is not found to be the case. It is true that the sap of certain species will flow more freely from wounds made early in the spring, but this is due probably to the roots becoming active before the leaves are out, thus subjecting the sap to pressure. As soon as the buds begin to burst, this pressure is somewhat relieved by evaporation from the young leaves.

Table III shows the moisture per cent in green woods during different months of the year.

TABLE III.—PER CENT OF MOISTURE IN GREEN WOOD

Month	Arbor-vitae[a]	Douglas fir[b]	Average of 24 European hardwoods[c]	Average of 5 European conifers[c]	Chestnut[d]	Loblolly pine[e]	
						Sapwood	Heartwood
Jan.	..	40	47	60	91	Winter 109	58
Feb.	..	47	48	58			
March	..	49	44	59			
April	81	38	43	54	89	Spring 107	48
May	74	40	43	60			
June	84	33	41	61			
July	84	28	45	60	89	Summer 107	57
Aug.	77	39	..	..			
Sept.	70	..	43	58		Autumn 100	47
Oct.	87	34	..	..	88		
Nov.	80	42	40	58			
Dec.	90	39	..	..			

[a] Average of 50 poles cut each month near Metropolitan, Mich. From Forest Service *Circular* **136**, "The Seasoning and Preservative Treatment of Arbor-vitae Poles."

[b] Average of 200 ties cut each month (except September) near Tacoma, Wash. From Forest Service *Circular* **146**, "Experiments with Railway Cross-ties."

[c] "Die Technischen Eigenschaften der Hölzer," DR. H. NÖRDLINGER, 1860.

[d] Average of 1,600 poles cut in the eastern United States, compiled from Forest Service *Circular* **103**, "Seasoning of Telephone and Telegraph Poles."

[e] Average of several thousand cross-arms cut in North Carolina, compiled from Forest Service *Circular* **151**, "The Preservative Treatment of Loblolly Pine Cross-arms."

The sapwood of green trees often contains over 100 per cent of moisture, and trees have been found in which the moisture content was over 250 per cent of the dry weight. In such cases the cell walls are fully saturated, and the cell cavities are almost filled with water. In the heartwood of some green conifers the moisture content is as low as 30 per cent.

According to Tiemann[1] there is a maximum amount of moisture which wood of any given specific gravity can hold. The curve in Fig. 23 shows this relation. For example, a piece of wood having a specific gravity of 1.54 (actually such wood does not exist) would be all wood substance and there would be no room for moisture; a piece of wood with a specific gravity of 0.40 could hold a maximum of 185 per cent moisture, based on the dry weight of the wood.

[1] Unpublished report.

The amount of moisture in air-dry woods[1] varies greatly, depending upon the length of seasoning, the climate, the size of the pieces, whether protected from the rain or not, and on the kind of wood. Thoroughly air-dry wood usually contains 12 to 15 per cent moisture, in the greater part of the United States, but often wood is considered air dry when it contains anywhere up to 30 per cent or even more moisture. In making tests on

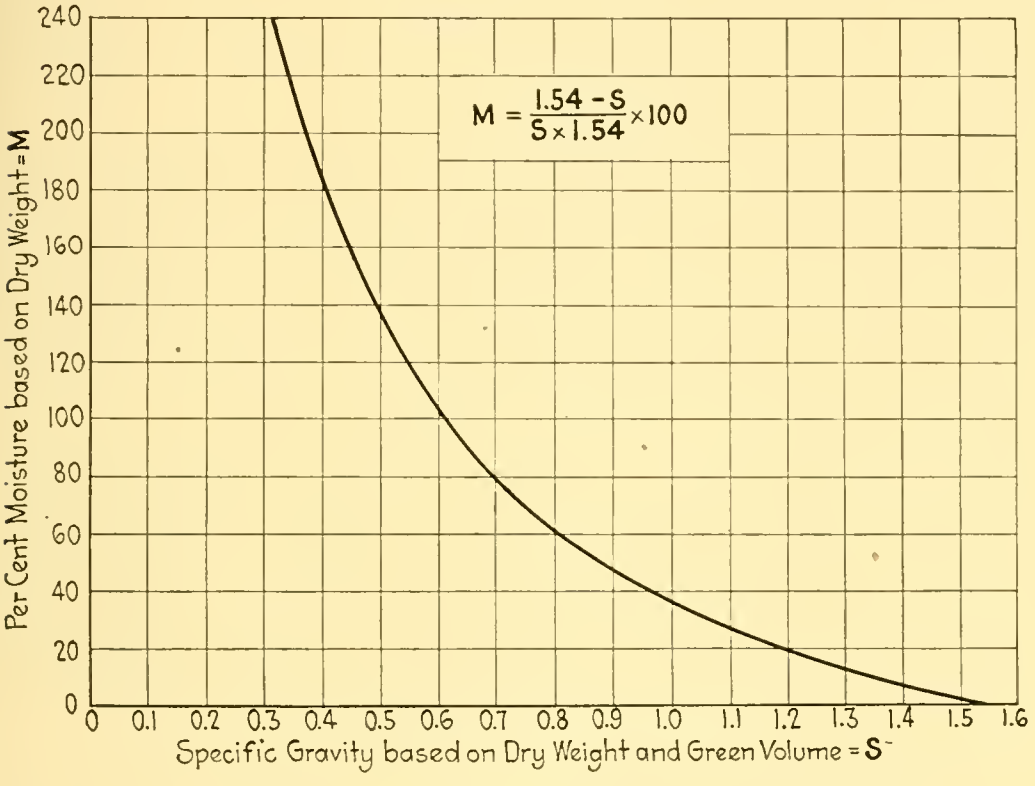


FIG. 23.—Limit of moisture possible with a given specific gravity.

timbers which had been air dried for 2 years, Forest Service investigators found that the average moisture content of two sections of longleaf pine timbers, one 12 by 12 inches and the other 8 by 16 inches, both 16 feet long, containing an average of 3 per cent sapwood, was 18 per cent in the outer shell extending halfway to the center; and of the remaining inner parts it was 25.7 per cent. This shows that large pieces do not reach their greatest possible air dryness in 2 years.

Kiln-dried wood usually has between 3 and 20 per cent moisture, although occasionally it may have more or less. Lumber kiln-dried to reduce the shipping weight only, may be no

[1] The term "air-dry wood" as here used does not include wood dried in buildings artificially heated.

drier than that seasoned in the yard. Lumber used for furniture, cabinets, and similar products should have from 4 to 6 per cent moisture; and parts of vehicles and other articles used outdoors and requiring tight joints from 7 to 9 per cent in the greater part of the United States.

22. Absorption of Moisture. (*a*) *From the Atmosphere.*— Dry wood will absorb moisture from damp air, and wet wood will give up some of its moisture in comparatively dry air. This property of taking on and giving off moisture is known as *hygroscopicity*. It is found in many other materials besides wood, for example, in cloth, glue, and soil.

Under ordinary atmospheric conditions wood will absorb or give off moisture until a balance is reached when no further change will take place. At first the rate of change is comparatively rapid, but it gradually slows up as the wood approaches the point of equilibrium, so that it takes considerable time for the moisture content to come into balance with the humidity of the air.

The length of time required for natural wood to reach equilibrium increases with the amount of moisture change necessary and with the size and density of the piece; and decreases with the temperature. End grain will take up and give off moisture more rapidly than side grain, and sapwood will change more rapidly than heartwood. The species of wood also makes some difference; for example, red oak responds more rapidly to atmospheric changes than white oak.

Since wood shrinks and swells with changes in moisture content, it may *appear* as if certain light woods or sapwood shrink and swell more than heavier woods or heartwood, when subjected to changed atmospheric conditions for a short time, but, in fact, they may be only changing moisture content more rapidly, and the total change in dimension in the course of time may be no more and even may be less.

There is a definite relation between the moisture content of wood and the relative humidity of the air when at equilibrium. This relation is shown by the curves in Fig. 24. For example, at 70° F. and a relative humidity of 68 per cent wet wood will dry down to about 13 per cent, and dry wood, which has not been subjected to a high degree of heat, will take on moisture to about 13 per cent. At higher temperatures this will be slightly less and at lower temperatures slightly more. It is interesting to note

that this relation is approximately the same for all woods. This might be expected when one considers that the substance of which wood is made is practically the same for all species.

Wood exposed to saturated air (100 per cent humidity) will absorb moisture indefinitely, or until saturated, although the absorption is very slow after the wood has taken on a considerable amount.

The hygroscopicity of wood can be reduced somewhat by subjecting it to high temperatures, as in kiln drying, heating it

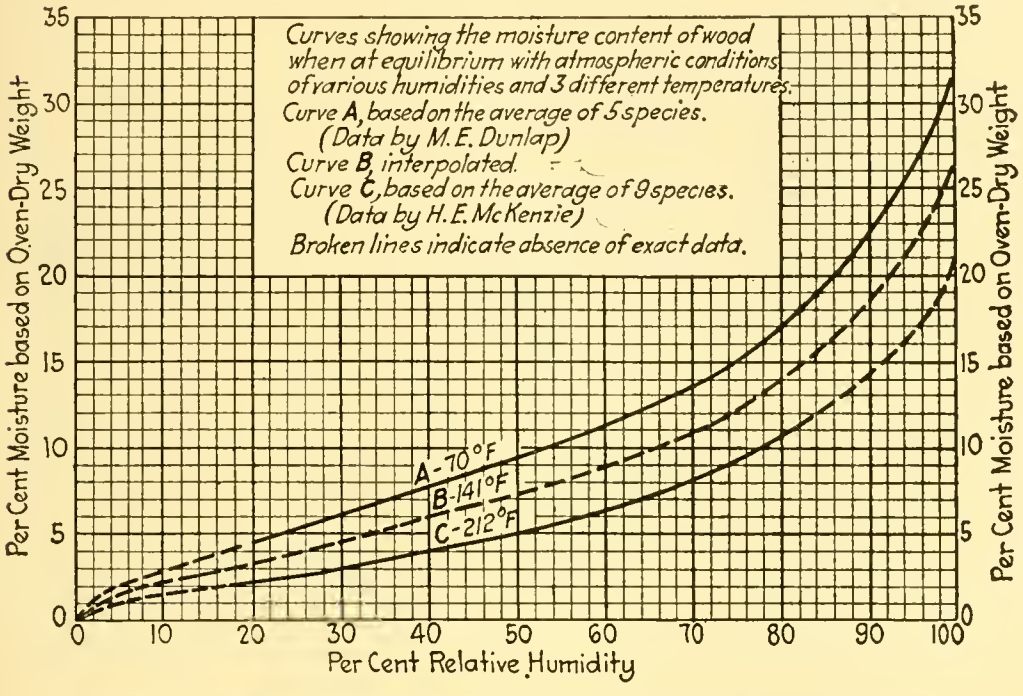


FIG. 24.—Relation of moisture content of wood to relative humidity.

in an oven or closed cylinder, or steaming it. Lumber dried in a kiln at high temperatures will not cause so much trouble in swelling as that which is dried at low temperatures. It is also claimed that boiling wood has a similar effect, but the author knows of no data that will substantiate this claim.

In a series of tests made in cooperation with the Yale Forest School[1] pieces of wood air dried 1 year, then kiln dried at temperatures of from 145 to 274°F., and then placed outdoors but protected from the weather for another year, absorbed moisture outdoors up to an average of 9.1 per cent, while similar pieces air dried 2 years, but not placed in a kiln, dried to 12.3 per

[1] *Hardwood Record*, Nov. 25, 1913.

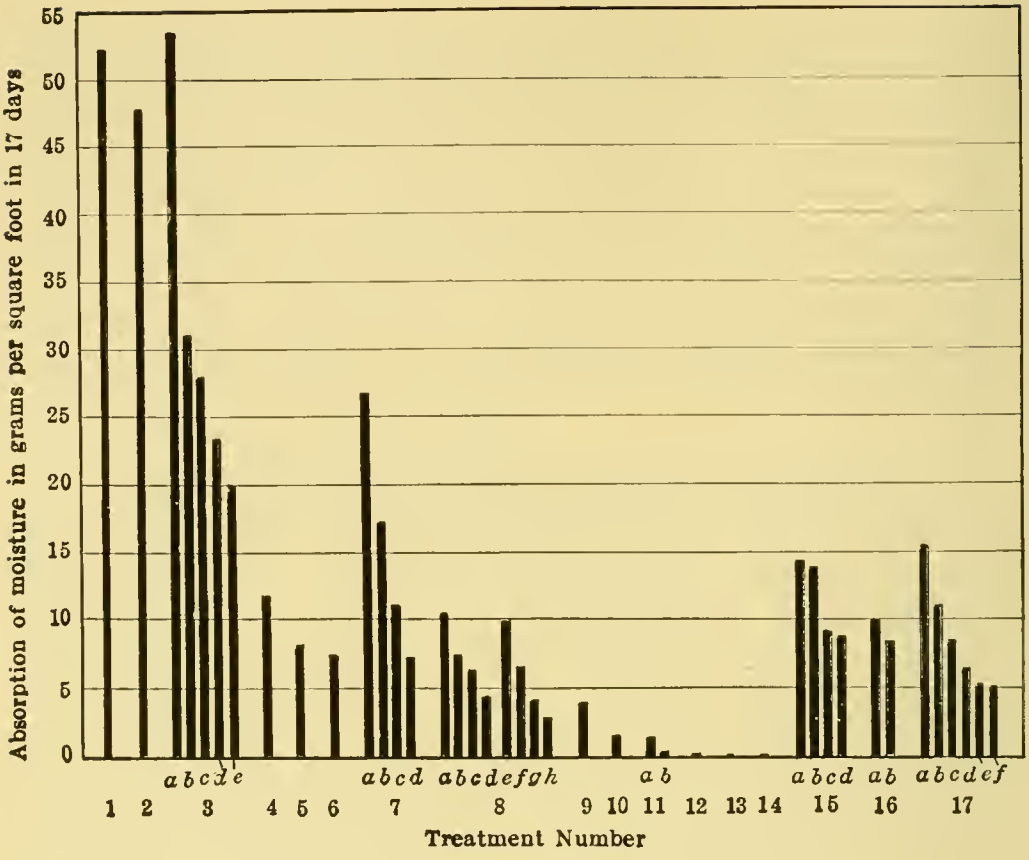


FIG. 25.—The relative effectiveness of different materials and methods of treatment in preventing the absorption of moisture by wood when exposed for 17 days to a humidity of 95 to 100 per cent.

TREATMENT.

1. Natural wood—no treatment.
2. 5 coats of linseed oil plus 2 coats of wax.
3. Impregnation treatments—
   - *a* Linseed oil (soaking).
   - *b* Paraffin and gasoline (vacuum and pressure).
   - *c* Beeswax (vacuum and pressure).
   - *d* Spar varnish (vacuum and pressure).
   - *e* Cellulose varnish (vacuum and pressure).
4. 3 coats of cellulose varnish.
5. Filler plus 3 coats of orange shellac.
6. Filler plus 3 coats of rubbing varnish.
7. Filler plus 3 coats of spar varnish.
   - *a* Poorest of 43 varnishes tested.
   - *b* Average of 43 varnishes tested.
   - *c* Average of 10 best varnishes tested.
   - *d* Best varnish tested.
8. Enamels—Filler plus—
   - *a* 2 coats enamel (red-lead pigment) plus varnish.
   - *b* 2 coats enamel (aluminum powder) plus varnish.
   - *c* 2 coats enamel (white-lead pigment) plus varnish.
   - *d* 2 coats enamel (barytes pigment) plus varnish.
   - *e* 3 coats commercial enamel (average of 11 brands).
   - *f* 3 coats commercial enamel (best brand).
   - *g* 2 coats laboratory mixture plus varnish (average of 10 best mixtures).
   - *h* 3 coats laboratory mixture plus varnish (best laboratory mixture.)
9. Filler plus 3 coats of shellac and aluminum powder.
10. 5 coats of bakelite plus 5 coats of varnish.
11. Metal leaf coatings—Filler plus shellac or varnish under coat plus varnish size plus aluminum leaf plus 2 coats of varnish shellac or enamel.
    - *a* Average of all types.
    - *b* Best type.
12. Sprayed with copper or aluminum and coated with 3 coats of varnish.
13. Electroplated with copper.
14. Vulcanized rubber coating (1 small specimen tested).
15. Forced drying (filler and 3 coats)—
    - *a* Average of 23 varnishes (room dried).
    - *b* Same varnishes (dried at 110° F.).
    - *c* Average of 5 enamels (room dried).
    - *d* Same enamels (dried at 110° F.).
16. Brushed versus dipped coatings—
    - *a* Filler plus 3 brushed coats (average of 7 varnishes).
    - *b* Filler plus 3 dipped coats (average of same varnishes).
17. Filler plus different numbers of coatings—
    - *a* 2 brushed coats.
    - *b* 4 brushed coats.
    - *c* 6 brushed coats.
    - *d* 8 brushed coats.
    - *e* 10 brushed coats.
    - *f* 12 brushed coats.

cent. Evidently the kiln drying had reduced the moisture holding capacity of the wood.

The higher the temperature and the longer it is maintained the more the hygroscopicity is reduced, but severe treatments of this nature may damage the lumber. Preservative treatment with creosote and soaking the wood in hot paraffin also have been found to reduce the capacity of the wood to absorb moisture.

Painting or varnishing wood, or soaking it in linseed oil, does not reduce its hygroscopicity but reduces the rate at which it absorbs moisture; that is, woods so treated require more time to absorb a certain amount of moisture from the atmosphere. Since damp weather usually prevails for comparatively short periods only, wood coated with paint, oil, varnish, or shellac will not swell so much as unprotected wood during a few days of rainy weather. The effectiveness of various coatings and impregnations on retarding the absorption of moisture from damp air for a period of 17 days is shown graphically in Fig. 25.[1]

(*b*) *From Water.*—Dry wood will absorb moisture rapidly when placed in water or in contact with a moist material as the soil or green timbers.[2] The rate of absorption, while rapid at first, gradually becomes slower so that a long period is required to saturate large pieces fully. Air-dry pieces of Douglas fir, 4 by 4 inches by 4 feet long, were still absorbing moisture after 4 months of complete immersion at the Forest Products Laboratory. Logs kept in water will eventually absorb enough water so that the cell cavities will become more or less filled and, the cell walls being heavier than water, the logs will sink or "waterlog." It usually takes several years for pine to waterlog, but hardwoods will sink sooner.

Sapwood absorbs moisture more readily than heartwood; consequently, logs with a large proportion of sapwood will waterlog more quickly, as a rule, than those of the same species with less sapwood. Because sapwood allows water to pass through

[1] From DUNLAP, M. E., "Moisture Resistant Finishes for Airplane Woods." *Rept.* 85 of the National Advisory Committee of Aeronautics.

[2] The mutual attraction between wood and water causes a slight rise in temperature when dry wood absorbs moisture. The amount of heat so evolved was found to vary from 16.6 to 19.6 calories per gram of dry wood of sugar maple, beech, and longleaf yellow pine. This same amount of heat must be expended in removing the moisture from the cell walls of wood. From an unpublished report by DUNLAP, FREDERICK, Forest Assistant, Forest Products Laboratory.

rather readily, it cannot be used for tight cooperage or tanks, unless the staves are sized on the inside with an impervious material. Sapwood absorbs more of certain stains than heartwood and appears darker after staining.

End grain absorbs water much more rapidly than side grain, and the tangential faces more rapidly than the radial faces. Heavy woods absorb a smaller per cent in proportion to their weight of certain liquids than light woods in a short period of time. Hence, woods with alternating layers of dense summerwood and soft springwood will absorb more stain in the springwood, in this way bringing out the figure.

23. Penetration of Woods by Liquids.[1]—The extent to which liquids enter wood, either by being absorbed or by being forced in under pressure, has practical application in the impregnation of woods with preservatives, fire-retardants, and waterproofing materials; in staining woods so as to give them a uniform color throughout; in gluing wood; in using solvents for extracting resin and other materials from wood; and in cooking chips in chemical solutions in the manufacture of pulp.

In considering this subject it is necessary to distinguish between "absorption" and "penetration." The former refers to the amount of liquid taken up per cubic foot (or other unit) of wood, and the latter to the distance the liquid passes into the wood from the surface. The two go together to a certain extent but are not necessarily proportional. For instance, under identical conditions creosote has been forced into western larch heartwood and white spruce heartwood, both showing about the same penetration on all sides, but the larch showed an absorption of 15.7

[1] For further references, see:

TEESDALE, C. H., "Relative Resistance of Various Conifers to Injection with Creosote." United States Department of Agriculture *Bull.* **101.**

TEESDALE, C. H., and MACLEAN, J. D., "Relative Resistance of Various Hardwoods to Injection with Creosote." United States Department of Agriculture *Bull.* **606.**

BATEMEN, ERNEST, "A Visual Method for Determining the Penetration of Inorganic Salts in Wood." Forest Service *Circular* **190.**

TEESDALE, C. H., "The Absorption of Creosote by the Cell Walls of Wood." Forest Service *Circular* **200.**

TEESDALE, C. H., and MACLEAN, J. D., "Tests on the Absorption and Penetration of Coal Tar and Creosote in Longleaf Pine." United States Department of Agriculture *Bull.* **607.**

BAILEY, I. W., "The Preservative Treatment of Wood." *Forest Quarterly*, March, 1913.

pounds per cubic foot and the spruce only 6.4 pounds per cubic foot. These figures, however, apply to an individual case and should not be taken as typical for these species. In preserving wood, dyeing wood, and some other lines of work requiring impregnation of wood a thorough penetration usually is sought rather than a maximum absorption. In fact, in some wood-preserving processes—the so-called empty-cell processes—a certain amount of the preservative is withdrawn from the wood, after it has been forced in, for the sake of economy. This is accomplished, after the external pressure is relieved, by the expansion of air compressed in the wood ahead of the preservative.

The conditions that influence penetration are the pressure applied to the liquid, the time under pressure, the temperature, the character of the liquid, the species of wood, whether heartwood or sapwood, the direction of the grain, and the extent to which the wood is seasoned. If no pressure is applied, the penetrance is due to natural absorption and implies an affinity of the wood and the liquid for each other. It is probable that a high degree of penetration can be secured in all woods if enough pressure is applied and if the pressure is continued for a sufficient length of time. In practice, however, it is found that many woods effectively resist thorough penetration by some liquids at several hundred pounds pressure per square inch for 24 hours. In general, the hotter the liquid the further it will penetrate wood under a given pressure within a given time.

What little information is available on the subject indicates that water and watery solutions penetrate wood more easily than oily solutions, but detailed data are lacking. Some dyes penetrate just as far as the liquid in which they are dissolved, but others seem to be filtered out in passing through the outer layers of wood and will not penetrate to the interior.

It is interesting to note in this connection that when wood is placed in certain solutions it may absorb more of the material dissolved than of the water or whatever solvent is used, leaving the unabsorbed solution weaker than it was originally. This may be due to a chemical combination of the solute with the wood, or to whatever moisture there is in the wood becoming a part of the solution thereby weakening it.

Woods with open pores, such as red oak, slippery elm, tupelo gum, and birch are easily penetrated, but woods in which the pores are closed, or partly closed by tyloses or gums, as in the heartwood

of white oak, chestnut, red gum, and sugar maple, are penetrated with greater difficulty. No distinction as to penetrance can be made between ring-porous and diffuse-porous woods, or even between hardwoods and conifers as a class. As a rule sapwood is penetrated more easily than heartwood although in eastern hemlock and a few other species the heartwood is as easily penetrated with creosote as the sapwood.

If wood is submerged in a liquid and pressure applied to the liquid, it will always penetrate further in the direction of the grain than across the grain. In conifers having radial resin ducts (pines, spruces, larches, and Douglas fir) the radial penetration with creosote is considerably more than the tangential penetration and from one-fourth to three-fourths as great as the longitudinal penetration. In conifers without radial resin ducts and in hardwoods the radial and tangential penetrations of creosote are about equal, and range from one-twentieth to one one-hundred-twentieth of the longitudinal penetration.

The density of a species of wood does not govern the extent of its penetration by liquids although in creosoted conifers the dense summerwood nearly always shows better penetration and greater absorption than the adjacent springwood, except near the ends where the springwood also is easily penetrated.

Seasoned wood absorbs liquids more rapidly than green wood under the same conditions, and for this reason it usually is necessary to season timbers before a satisfactory preservative treatment can be given them.

It is believed by some that a preliminary soaking of timbers for a long time with subsequent seasoning increases the ease with which creosote can be forced into the wood. Experiments made at the Forest Products Laboratory on Douglas fir show that soaking the wood for a period of 4 months and then thoroughly air seasoning it did not increase the penetration or absorption of creosote.

CHAPTER III

THE PHYSICAL PROPERTIES OF WOOD (*Continued*)

24. Shrinking and Swelling.—One of the drawbacks to the use of wood is its tendency to shrink and swell. There is no practical way of preventing completely the shrinking and swelling of wood under ordinary atmospheric conditions. However, with a thorough understanding of the factors which govern shrinkage

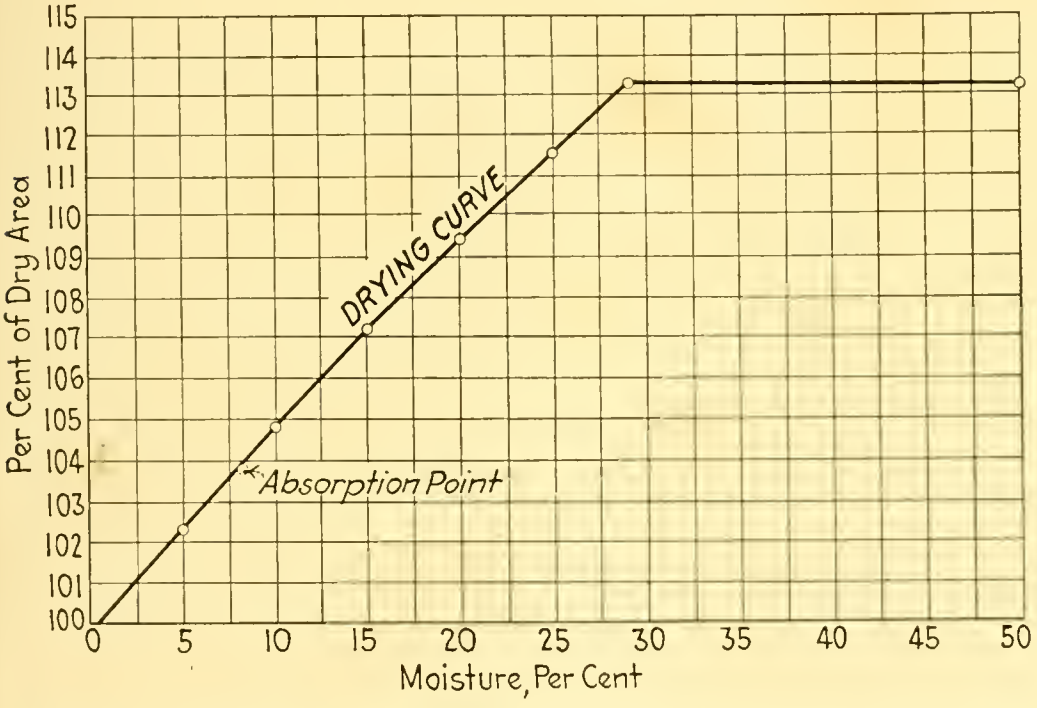


FIG. 26.—Relation of moisture content to the cross-section of small, clear specimens of western larch. The "fiber-saturation point" is at 29 per cent moisture. The "absorption point" indicates the per cent of moisture absorbed and the swelling of the specimens after exposure in the laboratory until a constant weight was reached after oven drying. (*From Forest Service Bull.* 122, "*Mechanical Properties of Western Larch.*")

the troubles which may result therefrom can largely be avoided. This is shown nowhere better than by the success with which wood is used in airplane propellers which must retain their shape although they may be subjected to atmospheric conditions varying from low humidities in heated buildings to rainy weather.

Wood does not shrink in drying until the fiber-saturation point is reached (which ranges from 20 to 35 per cent moisture); conversely when dry wood absorbs moisture, it does not swell after the fiber-saturation point is passed. This relation between shrinkage and moisture content is shown graphically in Fig. 26. In drying commercial sizes some shrinkage usually takes place before the average moisture content is below 35 per cent, but this is due to the surface layers drying below the fiber-saturation point while the interior still contains considerably more moisture.

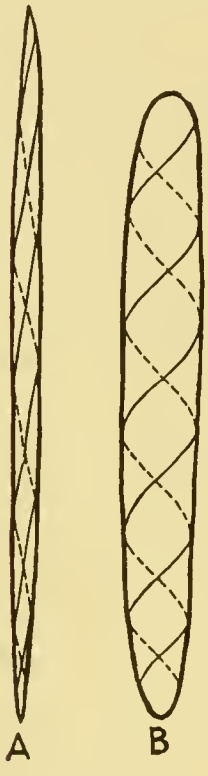


FIG. 27.—Diagrammatic illustrations of wood fibers showing the slope, or pitch, of the fibrils in the walls. In *A* the fibrils make a comparatively small angle, and in *B* a comparatively large angle with the axis of the fiber.

Heat increases the capacity of the fibers to absorb water and, therefore, raises the fiber-saturation point so that wood fully saturated when cold will swell still more when placed in hot water.

Shrinkage is due to contraction of the cell walls as the moisture leaves. Theoretically, the cell walls are made of fibrils which run spirally in the walls. The water in the cell walls is held principally between the fibrils. If the fibrils absorb any moisture, it is a comparatively small amount. These fibrils are too small to be seen with a microscope, but their probable orientation can be determined by the direction of checks and other markings in the cell wall. Usually these fibrils run nearly parallel with the axis of the cell, as in Fig. 27*A*. As the water leaves from the spaces between the fibrils they draw together in a direction almost at right angles to the axis of the cell. This produces considerable transverse shrinkage but little longitudinal shrinkage. Some woods have a large proportion of cells in which the fibrils make a greater angle with the axis, as illustrated in Fig. 27*B*, and in such woods the longitudinal shrinkage is appreciably greater. This is the case in so-called "compression wood" from the lower side of coniferous branches and leaning coniferous trees, in light tupelo gum and light cypress, and in the springwood of conifers and ring-porous hardwoods.

The shrinkage of wood usually is figured in per cent of the size of the wood when fully saturated, as in green

or resoaked specimens, so as to have a fixed size on which to base calculations.

25. Variation in Shrinkage.—The total shrinkage from the green to the oven-dry condition is different in different woods. Even in the same species it varies, depending upon the density and the method of drying; and in any individual piece it is different in different directions with respect to the axis of the tree.

Table IV gives the volumetric, radial, and tangential shrinkage of the more important American species and the ratio between the tangential and radial shrinkages.

In general, the denser woods shrink more than the lighter ones. This is true of different species as well as of light and heavy grades of the same kind of wood.[1]

Figure 28 shows the relation between the volumetric shrinkage and specific gravity of the more common American woods; Fig. 29 shows the relation for ash. From Fig. 28 it can be seen that some species shrink more than might be expected from their weight, for example, basswood; and others shrink less than their specific gravity would indicate, for example, osage orange. On account of its comparatively small amount of shrinkage, hardness, and resistance to decay, osage orange is considered the best wood for the felloes of wagon wheels for use in the arid southwest.

The shrinkage in volume in drying from the green to the oven-dry condition ranges from about 7 per cent in red cedar to 21 per cent in pignut hickory.

The shrinkage in different directions varies greatly, being least longitudinally and greatest tangentially. The shrinkage in length is negligible for most practical purposes. It usually varies from $\frac{1}{10}$ to slightly over $\frac{1}{3}$ of 1 per cent.[2] Thus a normal board 20 feet long may shrink from 0.24 to 0.08 inch in passing from the green to the oven-dry condition, but in practice, wood is not used in the oven-dry condition but usually is kiln dried or air dried, so only about one-half to two-thirds as much longitudinal shrinkage need be expected. Cross-grained pieces shrink more in length than straight-grained pieces of the same kind of wood.

[1] An exception to this general rule is that very light pieces of a species shrink more longitudinally than heavy pieces of the *same* species.

[2] Some light-weight tupelo has been found to shrink 1.25 per cent longitudinally, and yellow pine compression wood 3.25 per cent. The probable reason for this comparatively great longitudinal shrinkage lies in the orientation of the fibrils as explained in Art. **24.**

TABLE IV.—SHRINKAGE IN PER CENT OF GREEN VOLUME OF COMMON

Species	In volume	Radially	Tangentially	Ratio of tangential to radial shrinkage Radial = 1
Hardwoods				
Alder, red	12.6	4.4	7.3	1.61
Ash, black	15.2	5.0	7.8	1.56
White (forest grown)	12.6	4.2	6.5	1.55
White (second growth)	14.0	5.3	8.7	1.64
Aspen, trembling	11.1	3.3	6.9	2.09
Basswood	15.8	6.6	9.3	1.41
Beech	16.2	4.8	10.6	2.21
Birch, paper	16.3	6.6	8.8	1.33
Sweet	15.0	6.3	7.6	1.21
Yellow	16.8	7.4	9.0	1.22
Buckeye	12.0	3.5	7.8	2.23
Butternut	10.2	3.3	6.1	1.85
Cherry, black	11.5	3.7	7.1	1.92
Chestnut	11.6	3.4	6.7	1.97
Cottonwood	14.1	3.9	9.2	2.36
Cucumber	13.6	5.2	8.8	1.69
Dogwood, flowering	19.9	7.1	11.3	1.59
Elm, cork (or rock)	14.1	4.8	8.1	1.69
Slippery	13.8	4.9	8.9	1.82
White	14.4	4.2	9.5	2.26
Gum, Black	13.9	4.4	7.7	1.75
Cotton (or tupelo)	12.5	4.2	7.6	1.81
Red	15.0	5.2	9.9	1.90
Hackberry	13.8	4.8	8.9	1.86
Hickory, big shellbark	19.2	7.6	12.6	1.66
Mockernut	17.9	7.8	11.0	1.41
Pecan	13.6	4.9	8.9	1.82
Pignut	17.9	7.2	11.5	1.60
Shagbark	16.7	7.0	10.5	1.50
Holly	16.2	4.5	9.5	2.11
Hornbeam	18.6	8.2	9.6	1.17
Locust, black	9.8	4.4	6.9	1.57
Honey	10.8	4.2	6.6	1.57
Magnolia, evergreen	12.3	5.4	6.6	1.22
Mahogany, Central American	7.8	3.4	4.9	1.44
Maple, Oregon	11.6	3.7	7.1	1.92
Red	12.5	3.8	8.1	2.13
Silver	12.0	3.0	7.2	2.40
Sugar	14.5	4.8	9.2	1.92
Oak, bur	12.7	4.4	8.8	2.00
California black	12.1	3.6	6.6	1.83
Canyon live	16.2	8.0	14.3	1.79
Chestnut	16.7	5.5	9.7	1.76
Cow	19.4	5.9	9.2	1.56
Laurel	19.0	3.9	9.5	2.44
Pacific post	13.4	4.2	9.0	2.14
Post	16.2	5.4	9.8	1.81
Red	14.2	3.9	8.3	2.13

AMERICAN WOODS IN DRYING FROM THE GREEN TO THE OVEN-DRY CONDITION

Species	In volume	Radially	Tangentially	Ratio of tangential to radial shrinkage Radial = 1
Oak, Spanish highland	16.3	4.5	8.7	1.93
Spanish lowland	16.4	5.2	10.8	2.08
Water	16.4	4.2	9.3	2.21
White	15.8	5.3	9.0	1.70
Willow	18.9	5.0	9.6	1.92
Yellow	14.2	4.5	9.7	2.16
Persimmon	18.3	7.5	10.8	1.44
Poplar, yellow	11.4	4.1	6.9	1.68
Sassafras	10.3	4.0	6.2	1.55
Sycamore	14.2	5.1	7.6	1.49
Walnut, black	11.3	5.2	7.1	1.37
Willow, black	13.8	2.6	7.8	3.00
Conifers				
Cedar, incense	7.6	3.3	5.7	1.73
Northern white	7.0	2.1	4.9	2.33
Port Orford	10.7	5.2	8.1	1.56
Western red	8.1	2.5	5.1	2.04
Cypress, bald	10.7	3.8	6.0	1.58
Fir, Douglas (Rocky Mountain)	10.6	3.6	6.2	1.72
Douglas (Pacific Coast)	12.6	5.0	7.9	1.58
Fir, amabilis	14.1	4.5	10.0	2.22
Balsam	10.8	2.8	6.6	2.36
Grand	10.6	3.2	7.2	2.25
Noble	13.6	4.9	9.1	1.86
White	10.2	3.4	7.0	2.06
Hemlock, eastern	10.4	3.0	6.4	2.13
Western	11.6	4.5	7.9	1.76
Larch, western	13.2	4.2	8.1	1.93
Pine, jack	10.4	3.4	6.5	1.91
Loblolly	12.6	5.5	7.5	1.36
Lodgepole	11.5	4.5	6.7	1.49
Longleaf	12.3	5.3	7.5	1.42
Norway	11.5	4.6	7.2	1.57
Shortleaf	12.6	5.1	8.2	1.61
Slash	12.7	5.9	7.5	1.27
Sugar	8.4	2.9	5.6	1.93
White, eastern	7.8	2.2	5.9	2.68
White, western	11.5	4.1	7.4	1.80
Yellow, western	10.0	3.9	6.4	1.64
Redwood	6.3	2.7	4.2	1.55
Spruce, Engelmann	10.4	3.4	6.6	1.94
Red	11.8	3.8	7.8	2.05
Sitka	11.2	4.5	7.4	1.64
White	14.8	3.7	7.3	1.97
Tamarack	13.6	3.7	7.4	2.00
Yew, western	9.7	4.0	5.4	1.35

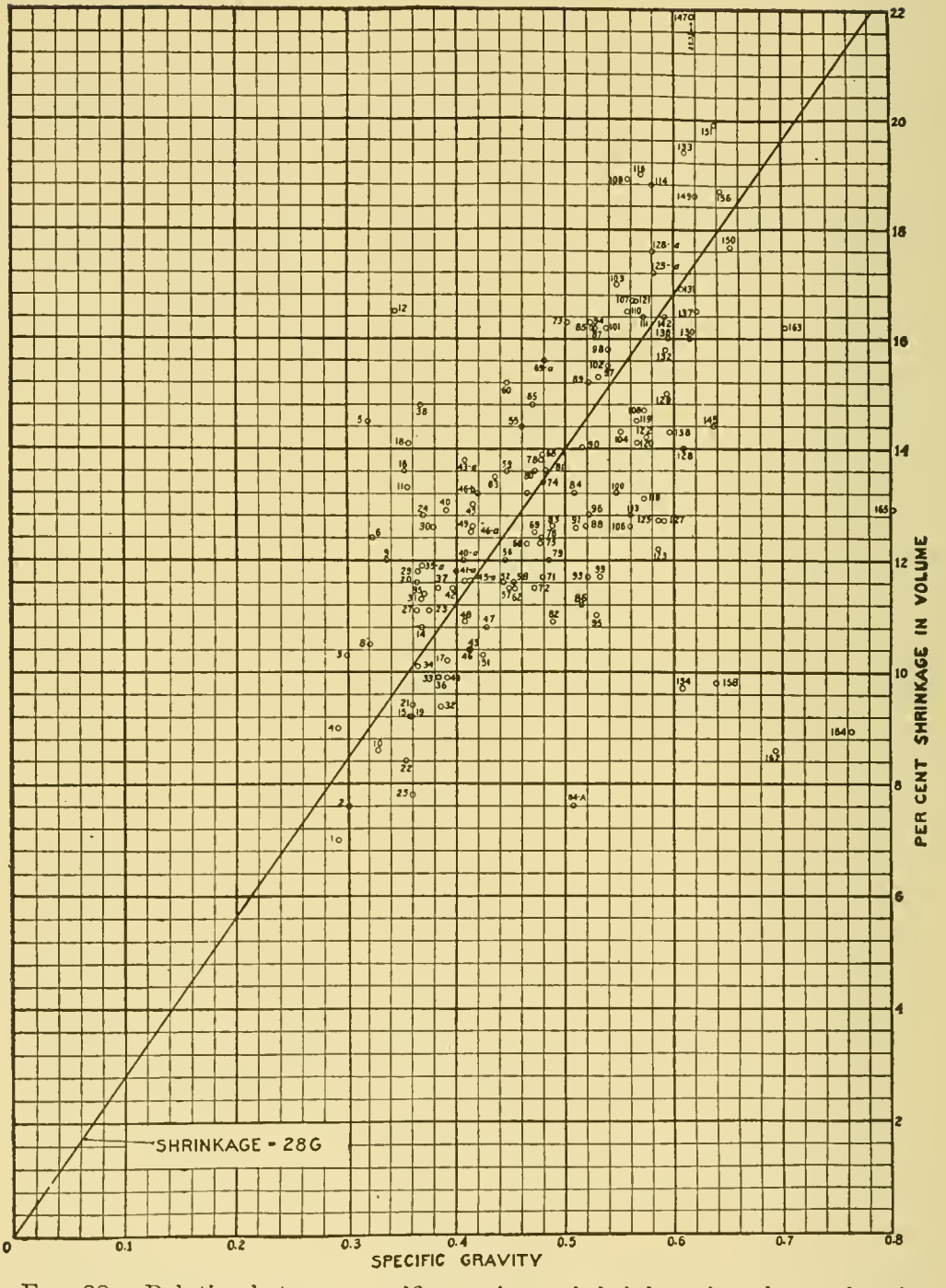


FIG. 28.—Relation between specific gravity and shrinkage in volume of native woods in drying from the green to the oven-dry condition. For legend, see pages 55 and 56. (*Courtesy, Forest Products Laboratory.*)

List of Species and Reference Numbers for Fig. 28

Hardwood

Species	Locality	Reference No.
Alder, red	Washington	30
Ash:		
Biltmore	Tennessee	91
Black	Michigan	60
Black	Wisconsin	70
Blue	Kentucky	99
Green	Louisiana	93
Green	Missouri	100
Pumpkin	Missouri	79
White	Arkansas	106
White	New York	128
White	West Virginia	83
Aspen	Wisconsin	23
Largetooth	Wisconsin	20
Basswood	Pennsylvania	12
Basswood	Wisconsin	5
Beech	Indiana	110
Beech	Pennsylvania	98
Birch:		
Paper	Wisconsin	73
Sweet	Pennsylvania	129
Yellow	Pennsylvania	107
Yellow	Wisconsin	103
Buckeye, yellow	Tennessee	9
Buckthorn, cascara	Oregon	84*a*
Butternut	Tennessee	27
Butternut	Wisconsin	21
Cherry:		
Black	Pennsylvania	72
Wild red	Tennessee	24
Chestnut	Maryland	46
Chestnut	Tennessee	40
Chinquapin, western	Oregon	46*b*
Cottonwood, black	Washington	6
Cucumber tree	Tennessee	59
Dogwood:		
Flowering	Tennessee	151
Western	Oregon	125*a*
Elder, pale	Oregon	69*a*
Elm:		
Cork	Wisconsin, Marathon County.	126
Cork	Wisconsin, Rusk County.	
Slippery	Indiana	102
Slippery	Wisconsin	74
White	Pennsylvania	55
White	Wisconsin	53
Greenheart		165
Gum:		
Black	Tennessee	68
Blue (Eucalyptus)	California	147
Cotton	Louisiana	76
Red	Missouri	54
Hackberry	Indiana	90
Hackberry	Wisconsin	78
Haw, pear	Wisconsin	146
Hickory:		
Big shellbark	Mississippi	135
Big shellbark	Ohio	154
Bitternut	Ohio	139
Mockernut	Mississippi	144
Mockernut	Pennsylvania	159
Mockernut	West Virginia	155
Nutmeg	Mississippi	112
Pignut	Mississippi	148
Pignut	Ohio	157
Hickory—*Continued.*		
Pignut	Pennsylvania	160
Pignut	West Virginia	161
Shagbark	Mississippi	140
Shagbark	Ohio	152
Shagbark	Pennsylvania	143
Shagbark	West Virginia	153
Water	Mississippi	141
Holly, American	Tennessee	87
Hornbeam	Tennessee	149
Laurel, mountain	Tennessee	145
Locust:		
Black	Tennessee	158
Honey	Indiana	162
Madrona	California	101
Madrona	Oregon	128*a*
Magnolia	Louisiana	66
Maple:		
Oregon	Washington	58
Red	Pennsylvania	69
Red	Wisconsin	92
Silver	Wisconsin	56
Sugar	Indiana	104
Sugar	Pennsylvania	108
Sugar	Wisconsin	124
Oak:		
Bur	Wisconsin	125
California black	California	80
Canyon live	California	163
Chestnut	Tennessee	121
Cow	Louisiana	133
Laurel	Louisiana	116
Post	Arkansas	130
Post	Louisiana	137
Red	Arkansas	119
Red	Indiana	118
Red	Louisiana	117
Red	Tennessee	97
Spanish Highland	Louisiana	94
Spanish Lowland	Louisiana	142
Swamp white	Indiana	150
Tanbark	California	115
Water	Louisiana	111
White	Arkansas	132
White	Indiana	138
White	Louisiana, Richland Parish.	136
White	Louisiana, Winn Parish.	131
Willow	Louisiana	109
Yellow	Arkansas	122
Yellow	Wisconsin	105
Osage orange	Indiana	164
Poplar, yellow (tulip tree)	Tennessee	35
Rhododendron, great	Tennessee	85
Sassafras	Tennessee	51
Serviceberry	Tennessee	156
Silverbell tree	Tennessee	49
Sourwood	Tennessee	89
Sumac, staghorn	Wisconsin	61
Sycamore	Indiana	63
Sycamore	Tennessee	65
Umbrella, Fraser	Tennessee	45
Willow:		
Black	Wisconsin	11
West[illegible]	Oregon	43*a*
Witch ha[illegible]	Tennessee	114

LIST OF SPECIES AND REFERENCE NUMBERS FOR FIG. 28—*Continued*

Conifers

SPECIES	LOCALITY	REFERENCE No.
Cedar:		
Incense	California	26
Western red	Montana	2
Western red	Washington	10
White	Wisconsin	1
Cypress, bald	Louisiana	62
Douglas fir	California	45*a*
Douglas fir	Oregon	67*a*
Douglas fir	Washington, Chehalis County.	46*a*
Douglas fir	Washington, Lewis County.	75
Douglas fir	Washington, and Oregon	67
Douglas fir	Wyoming	84
Fir:		
Alpine	Colorado	4
Amabilis	Oregon	39
Amabilis	Washington	18
Balsam	Wisconsin	14
Grand	Montana	36
Noble	Oregon	16
White	California	17
Hemlock:		
Black	Montana	47
Eastern	Tennessee	52
Eastern	Wisconsin	15
Western	Washington	50
Larch, western	Montana	84
Larch, western	Washington	64
Pine:		
Jack	Wisconsin	43
Jeffrey	California	33
Loblolly	Florida	88
Lodgepole	Colorado	31
Lodgepole	Montana, Gallatin County.	35*a*
Lodgepole	Montana, Granite, County.	41*a*
Pine—*Continued.*		
Lodgepole	Montana, Jefferson County.	40*a*
Lodgepole	Wyoming	34
Longleaf	Florida	123
Longleaf	Louisiana, Lake Charles.	113
Longleaf	Louisiana, Tangipahoa Parish.	96
Longleaf	Mississippi	95
Norway	Wisconsin	57
Pitch	Tennessee	71
Pond	Florida	86
Shortleaf	Arkansas	77
Slash	Florida	127
Sugar	California	22
Table mountain	Tennessee	82
Western white	Montana	42
Western yellow	Arizona	19
Western yellow	California	37
Western yellow	Colorado	41
Western yellow	Montana	32
White	Wisconsin	25
Redwood	California, Albion.	28
Redwood	California, Korbel.	13
Spruce:		
Engelmann	Colorado, Grand County.	8
Engelmann	Colorado, San Miguel County.	3
Red	New Hampshire.	44
Red	Tennessee	29
White	New Hampshire	7
White	Wisconsin	38
Tamarack	Wisconsin	81
Yew, western	Washington	134

The radial shrinkage of our commercial woods ranges from about 2 per cent to 8.5 per cent. The tangential shrinkage is from 1¼ to 3¾ times as much as the radial shrinkage, and ranges from 4.2 per cent to about 14 per cent, as shown in Table IV.

The lesser radial shrinkage of wood is due to the medullary rays in which the cells lie with their longest axes at right angles to the grain of the wood. See Figs. 3 and 4. These cells, like other wood cells, shrink only very slightly in length; consequently, they hold the fibers from shrinking to their full extent radially. In oak some of the rays are as much as 4 inches in height. In other species they are much smaller but very numerous. These rays offer an effective but not complete resistance to the radial shrinkage of the fibers, while the tangential shrinkage is unhindered.

In general, woods dried slowly under warm humid conditions shrink more than the same kinds dried rapidly. When the moisture leaves the wood rapidly, certain parts become drier than others but are prevented from shrinking correspondingly and, hence, become set in an expanded condition and full shrinkage cannot take place. This is what happens in casehardened lumber, as will be explained in greater detail in Art. **26.**

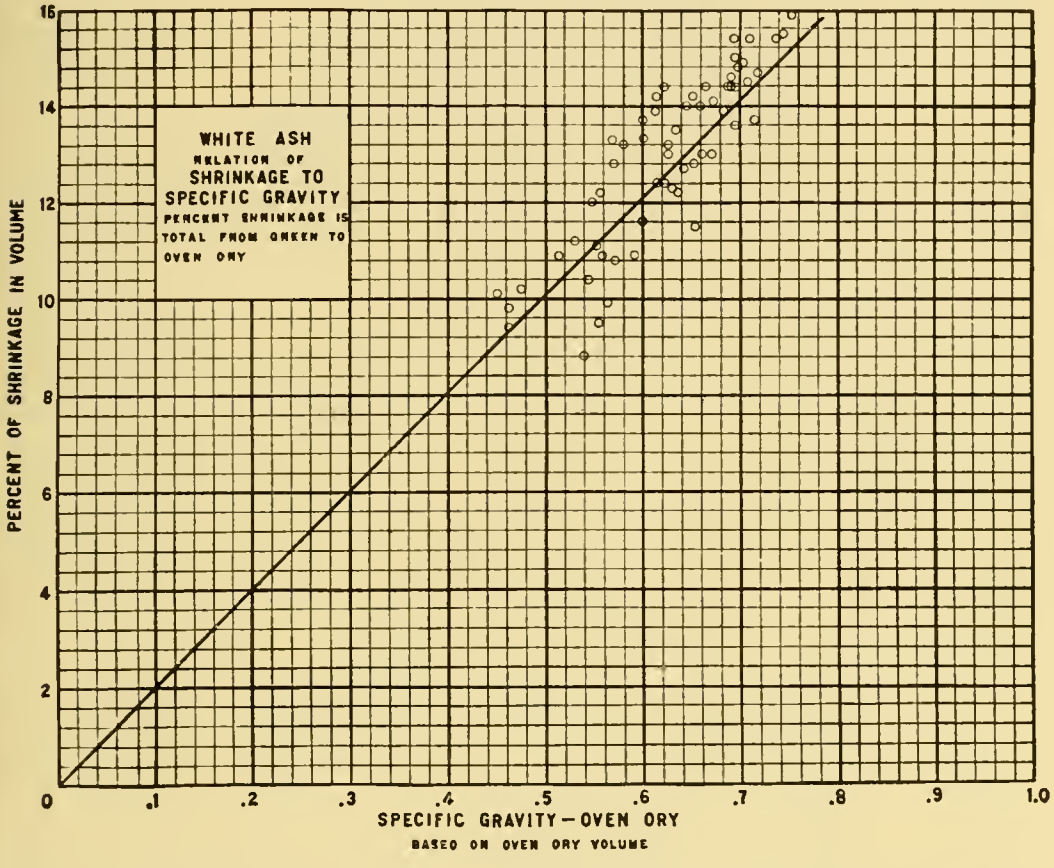


FIG. 29.—Relation of shrinkage to specific gravity in white ash. (*Courtesy, Forest Products Laboratory.*)

As already stated in Art. **22** high temperatures reduce the hygroscopicity of wood. The effect of this on the swelling of wood is shown in Table V, which is based on tests made on ash lumber at the Forest Products Laboratory. Pieces of ash were steamed for various periods at 28 pounds pressure (= 271.3° F). They were then hung indoors in a heated building until in equilibrium with atmospheric conditions, after which they were placed outdoors until again in equilibrium. The pieces steamed for 20 hours swelled only half as much as the pieces not steamed.

TABLE V.—CALCULATED SWELLING OF AN 8-INCH ASH BOARD IN CHANGING FROM INDOORS TO OUTDOORS

Treatment	Swelling
Natural wood	1 9/64 inch
Wood steamed at 28 pounds pressure 5 hours	9/64 inch
Wood steamed at 28 pounds pressure 10 hours	8/64 inch
Wood steamed at 28 pounds pressure 16 hours	6/64 inch
Wood steamed at 28 pounds pressure 20 hours	5/64 inch

It is claimed by some woodworkers that wood which has been in water for a long time will not shrink and warp so much in drying and will not "work" so much subsequently with changes in atmospheric humidity as wood which has been kept on land. Japanese craftsmen store high-grade lumber under water for several years in order to reduce its "working" and to darken it. The only scientific data available on the effect of "water curing" on the properties of wood are those collected by an Austrian investigator[1] who found that leaving logs in fresh water for 1½ to 3½ years slightly decreased the shrinkage of some species but not of all while drying, and also slightly decreased the hygroscopic properties of the air-dried wood but not enough to justify the long immersion.

The impregnation of wood with a sugar solution reduces its shrinking and swelling. This treatment is known as the Powell process. It has been experimented with in foreign countries as a means of preserving wood against decay and "white ants."

Although usually considered objectionable, the swelling of wood is occasionally turned to advantage; for example, in the temporary tightening of wagon wheel tires on felloes, ax handles in blades, and staves in tanks and barrels. It is said that before explosives were used in quarrying it was customary to drill a series of holes in the rock along a line on which cleavage was desired. These holes were fitted with dry wooden pegs which were then moistened. The swelling of the pegs exerted sufficient force to split the rock. It is a well-known fact that the force exerted by the swelling of wood is great enough to crush the wet

[1] JANKA, GABRIEL, "Die Einwirkung von Süss und Salzwässern auf die gewerblichen Eigenschaften der Hauptholzarten." *Mitteilung aus dem Förstlichen Versuchswessen Österreichs*, vol. XXXIII, 1907.

fibers transversely. Even in the weakest of native woods this amounts to over 200 pounds per square inch.

26. Some Effects of Uneven Shrinkage.—Uneven shrinkage is due to: (1) Differences in the rate of drying in different parts of the same piece, (2) the shrinkage not being the same in different

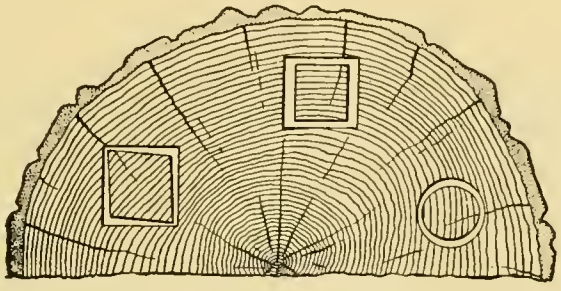


FIG. 30.—Distortion in shape of wood as it dries. (*From United States Department of Agriculture Bull.* 510, "*The Seasoning of Wood.*")

directions, and (3) variations in the density of a piece of wood. On account of its peculiar structure and the usual methods of drying, the shrinkage of wood is bound not to be uniform. This results in a change in shape, checking, or the formation of internal stresses, or a combination of these, as wood dries.

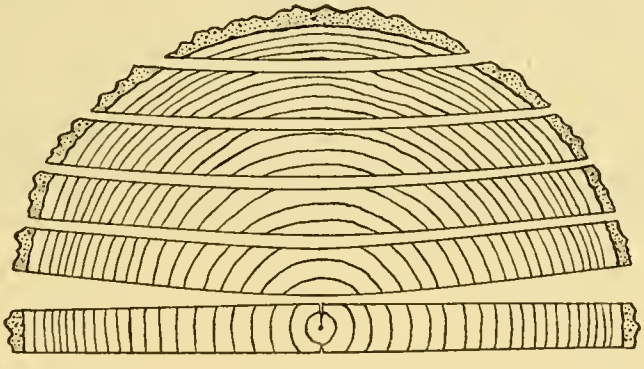


FIG. 31.—Cupping of plain-sawed lumber as it dries. Quarter-sawed board remains straight.

(*a*) *Change in Shape.*—Because of the differences in the radial and tangential shrinkages of wood, its cross-section becomes distorted as it dries. A square piece with the annual rings running practically parallel to two of its faces becomes oblong; a square piece with the annual rings running diagonally across the ends becomes diamond shaped; and a round piece becomes oval in drying. This distortion of shape is illustrated in Fig. 30. Because the radial and tangential shrinkages are not

equal, plain-sawed lumber shrinks more in width but less in thickness than quarter-sawed lumber.

Cupping of plain-sawed lumber, as shown in Fig. 31, is due to the side nearest the center of the tree being more nearly like a quarter-sawed surface than the other side, and, consequently, shrinking less in width. The cause of cupping of re-sawed lumber will be explained under the discussion of casehardening.

Twisting, or *warping*, is confined principally to woods with spiral or interlocked grain, although pieces of uneven density may also twist in seasoning. When a spirally grained log or timber dries out, its twist increases, whether it be right handed or

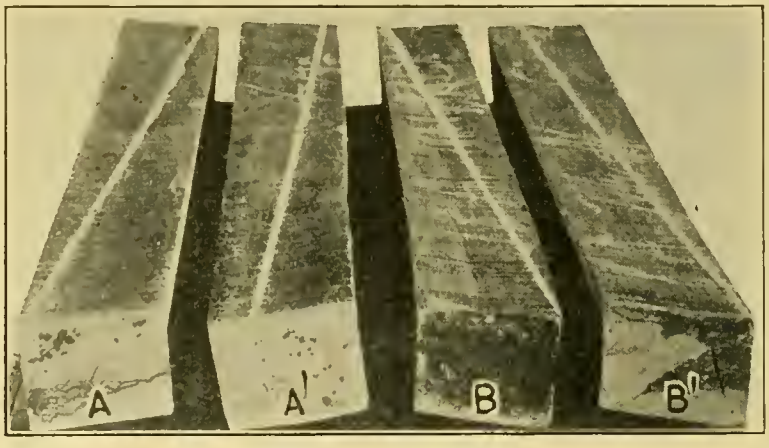


FIG. 32.—Oak bolsters twisted on account of spiral grain. The further ends rest flat on table top. Chalk lines indicate direction of grain. Sap side up.

left handed. A plain-sawed board or plank, or a dimension stick cut from a spirally grained log, also twists just as it would if it were a part of the whole log. This is illustrated in Fig. 32 which shows four oak wagon bolster blanks, A and A' being right spirally grained twisted to the right, and B and B' being left spirally grained twisted to the left.

Two factors are responsible for the twisting: (1) The shrinkage is greater across the grain than along the grain, and (2) the slope of the spiral is greater on the bark side than toward the center of the tree.[1] If the shrinkage were uniform throughout, or if the slope of the grain were the same throughout as it usually is in diagonally grained material, twisting would not occur.

Plain-sawed lumber cut from tree trunks with interlocked grain usually twists badly because the slope of the grain changes considerably from one side to the other. Quarter-sawed lumber

[1] Lumber may twist or bow when freshly cut from a log because of internal stresses which may be present in felled trees.

does not warp so much as plain-sawed lumber because the structure from one face to the other is more symmetrical.

Twisting is common in red gum, black gum, tupelo gum, cottonwood, sycamore, elm, and beech lumber, but may also occur in other kinds of lumber, especially in that from butt logs. The best preventive for cupping and twisting is to pile the lumber

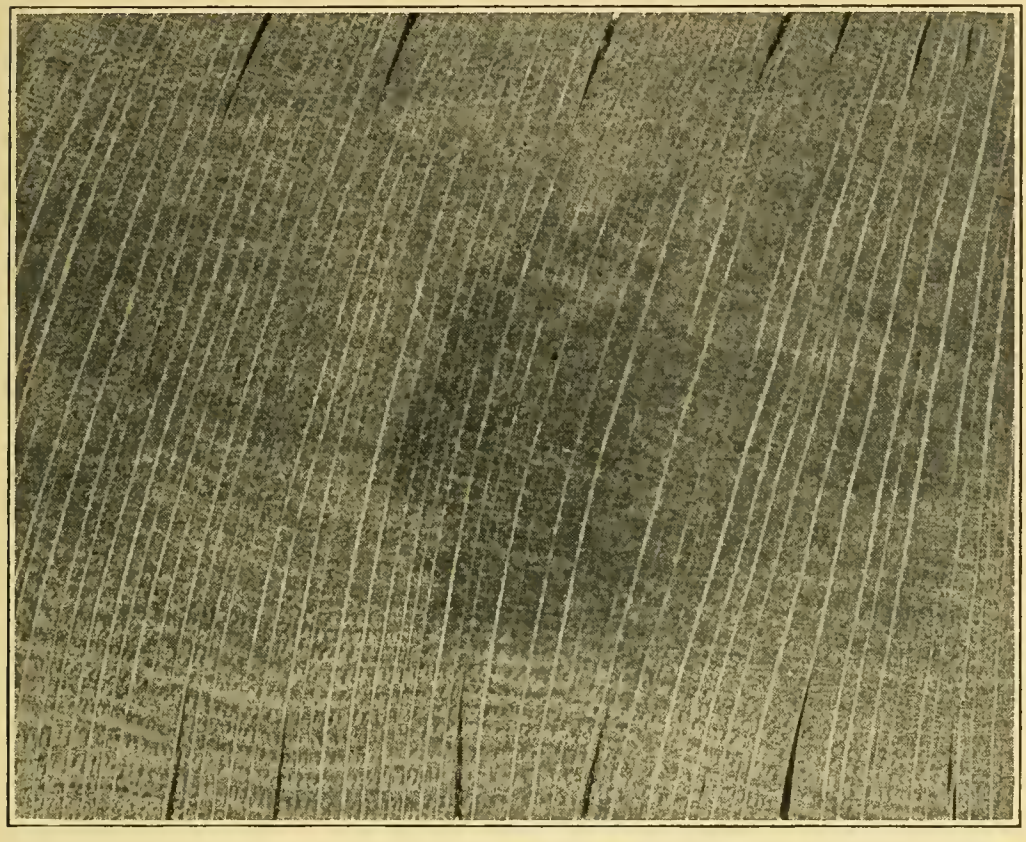


FIG. 33.—Cross-section of oak wagon bolster showing checks in surface layers while interior still is moist. Note how checks follow rays. (*Courtesy, Forest Products Laboratory.*)

carefully, placing the stickers about 2 feet apart, properly aligned, leaving no unsupported ends.

(*b*) *Checking.*—Uneven shrinkage often produces stresses great enough to tear the fibers apart transversely, and in rare cases longitudinally. If the surface of a piece of wood dries much faster than the interior, it usually checks. The checks extend principally along the medullary rays because the shrinkage is greatest in a direction at right angles to the rays, that is, tangentially, and because where the fibers and ray cells cross there is a weak plane which results from these elements having their greatest shrinkage at right angles to each other (Fig. 33). Hence, in

plain-sawed lumber the checks appear on the broad faces while in quarter-sawed lumber they occur principally in the edges, where they are less objectionable. Occasionally, the ends of timbers check tangentially as well as radially, but tangential checks caused from seasoning alone are finer than radial checks. Surface checks may close up as the interior of a piece of wood dries, but they do not heal up and may cause trouble later.

Timbers containing the pith of the tree are bound to check more or less, no matter how carefully they are dried, because the shrinkage along the annual rings is greater than from the surface toward the center. Also, as a rule, the surface dries more rapidly than the center, which contributes to the checking. In manufacturing wagon hubs and one-piece porch columns from round timbers the green material is bored out so as to permit greater radial shrinkage and also drying from the interior.

Birch has a distinct advantage over oak in the manufacture of wagon hubs in that it does not shrink much more tangentially than radially, as is shown in Table IV, and hence, has little tendency to check, whereas oak hubs must be dried very carefully in order to reduce checking to a minimum.

End checking may be reduced by coating the ends with one or two coats of linseed oil paint, asphalt paint, a commercial preparation known as lorac, or other highly impervious coatings which will adhere to damp wood. One of the most effective end coatings is clear rosin mixed with a little lampblack (60 to 1). This can be applied only in a molten condition, preferably by dipping the ends of the stock in the hot mixture. Another good coating, especially for kiln samples, is spar varnish mixed with enough barium sulphate to form a paste. This must be applied with a paddle. Whitewash, glue size, or a mixture of the two, and a hot paraffin spray are also used to prevent end checking in air seasoning. Boards or canvass sometimes are fastened over the ends of piles of lumber or timber to keep the ends from checking. On wide high-grade lumber, as mahogany, yellow poplar, and black walnut, cleats sometimes are nailed on the ends to prevent too rapid end drying and splitting.

Little can be done to prevent surface checking in lumber which is seasoning outdoors. If the lumber is piled close together it will not check on the faces, but it also will not season and may decay. Vehicle manufacturers usually pile heavy stock in partly closed

sheds. This reduces end and surface checking because the drying is more uniform than in the sun.

Wood can be kept indefinitely without checking by immersing it in water. This also keeps out decay, bluestain, and insects.

(*c*) *Internal Stresses.*—Lumber may be dried straight and to a uniform moisture content; but when it is cut up, the parts may curve or warp, without any change in moisture. Such distortion shows that internal stresses were formed in drying which manifest themselves as soon as their balance is upset. These internal stresses are due to parts of the piece being prevented from shrinking to their full capacity. A common form of internal stress results from what is known as *casehardening.*

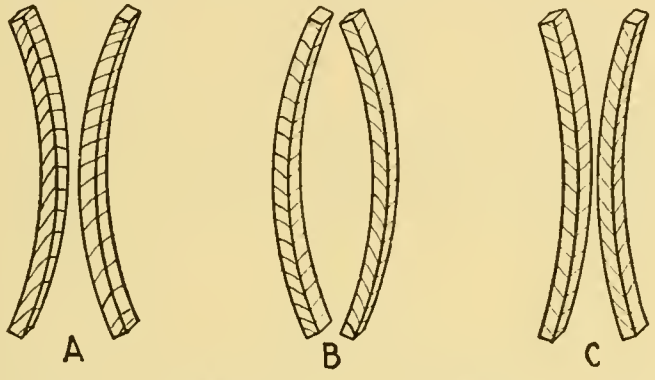


FIG. 34.—Cupping of resawed sections of boards. *A*, center, has higher moisture content than surface layers; *B*, uniformly dry but center in tension due to set condition in surface layers—casehardened; *C*, uniformly dry but surface layers in tension due to set being relieved in surface layers but not in interior—casehardening reversed.

Casehardening of wood does not mean a physical hardening of the outer layers as in metals, but rather a condition of the wood in which the surface layers are set without full shrinkage to a greater extent than the interior.

When green lumber, or even partly seasoned lumber, is dried comparatively rapidly at a relatively low humidity, whether in the open air or in a kiln, the outer part of each board dries much more rapidly than the interior and, consequently, tends to shrink sooner. The wetter interior retards the shrinkage of the outer layers and so they either check (Fig. 33), or dry in a stretched condition and become set without normal shrinkage, although retaining some of their tendency to shrink. If a board in this stage of drying is resawed through the middle, the halves will cup with their concave sides toward what formerly was the outside because this side is in tension. This condition is illustrated in Fig. 34*A*.

If the drying is continued, as it usually is, the interior of the board eventually becomes as dry as the outer layers, and tends to shrink normally. The outer fibers, being set in an expanded condition, in turn prevent the inner fibers from shrinking fully, although they will shrink enough to relieve the tension in the outer shell and even produce compression and close the surface checks. After this condition is reached, either the interior checks, or *honeycombs* as it is called (Fig. 35), or it dries in a stretched condition. Usually some set also takes place in the interior but not so much as in the surface layers. A board resawed in this condition will cup with the concave faces toward

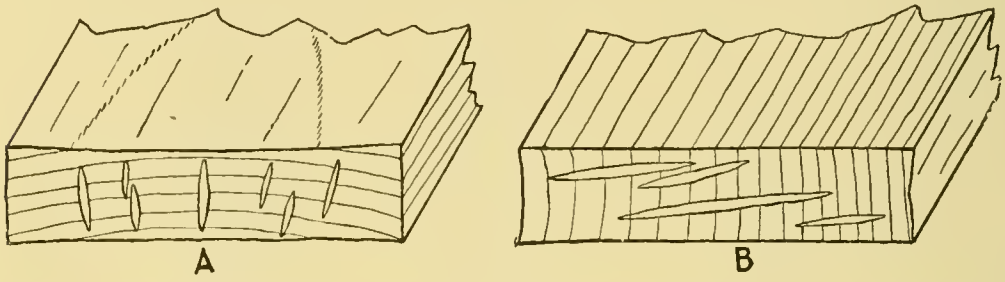


FIG. 35.—Honeycombing in lumber. *A*, in plain-sawed; *B*, in quarter-sawed board.

what was the center as soon as it leaves the saw. This condition is illustrated in Fig. 34*B*.

If the casehardened board is not fully dry in the interior, it may cup toward the outside or not cup either way immediately when resawed; but as the freshly exposed surfaces dry and shrink, the resawed halves will cup toward the inside.

According to this explanation of casehardening it ought to be possible after a casehardened board is dry throughout to relieve the compression in the surface layers and allow the interior to shrink and relieve its tension by moistening the surface layers and redrying them. This is precisely what can be done, and the usual method is to steam the lumber toward the end of the kiln run. If the air is saturated, the steaming requires from one-half to several hours. It is exceedingly difficult, however, to stop the steaming at the right moment. If the lumber is steamed too long, *all* the set will be taken out of the surface layers but not out of the interior (unless steamed for several days), and then in final drying the outer portion will dry in tension. Lumber so treated will cup toward the outside, when resawed (Fig. 34*C*), the same as insufficiently dried lumber, but there is no remedy

for this condition except to resoak the lumber to the center and start the drying over again. If the steaming is not carried far enough, the cupping toward the inside will not be fully overcome. The subject of steaming lumber will be taken up more fully in Chap. VIII.

Casehardened lumber will also cup if one side is dressed off deeper than the other, or for some reason the wood is not removed in equal amounts from both sides, as in scooping out chair seats.

Casehardened wood which is resawed is also liable to cause trouble on account of the difference in the hygroscopic properties of the two surfaces. The original outer surface shrinks and swells less than the resawed face; on the other hand, the outer surface is more quickly affected. Therefore, such lumber, even though dressed flat, may cup with certain changes in atmospheric humidity, although both surfaces are equally exposed.

Another objectionable feature of casehardened lumber is that if it ever becomes moist and redries slowly it will shrink more than it did in the first place because the set will become relieved to a greater or less extent.

27. Reducing Shrinking and Swelling to a Minimum During and After Manufacture.—No process has as yet been discovered for eliminating entirely the shrinking and swelling of wood, but in following the rules given below the "working" which results from changes in atmospheric humidity can be reduced to a minimum:

1. Have the wood dried to a uniform and proper moisture content before it is put through the woodworking machines so that it will neither give off nor take on much moisture from the air.
2. Use quarter-sawed lumber.
3. Use as light wood as will stand up under the conditions.
4. Use cross-banded material, that is, veneers glued together with the grain crossing.
5. Use wood which has been subjected to high temperatures. This, as previously stated, reduces the capacity of wood to absorb moisture.
6. Apply several coats of oil, varnish, enamel, shellac, or other protective coating to the finished article, or impregnate it with paraffin or creosote. These materials will reduce the change in volume if the wood is subjected to changed humidities for limited periods of time.

7. Keep the air in the shop, and even where the article is stored or used, at somewhere near the proper humidity.

28. Collapse.—In drying some woods, especially very wet western red cedar, redwood, swamp oak, red gum, willow, and eucalyptus, what appears to be abnormal shrinkage may result,

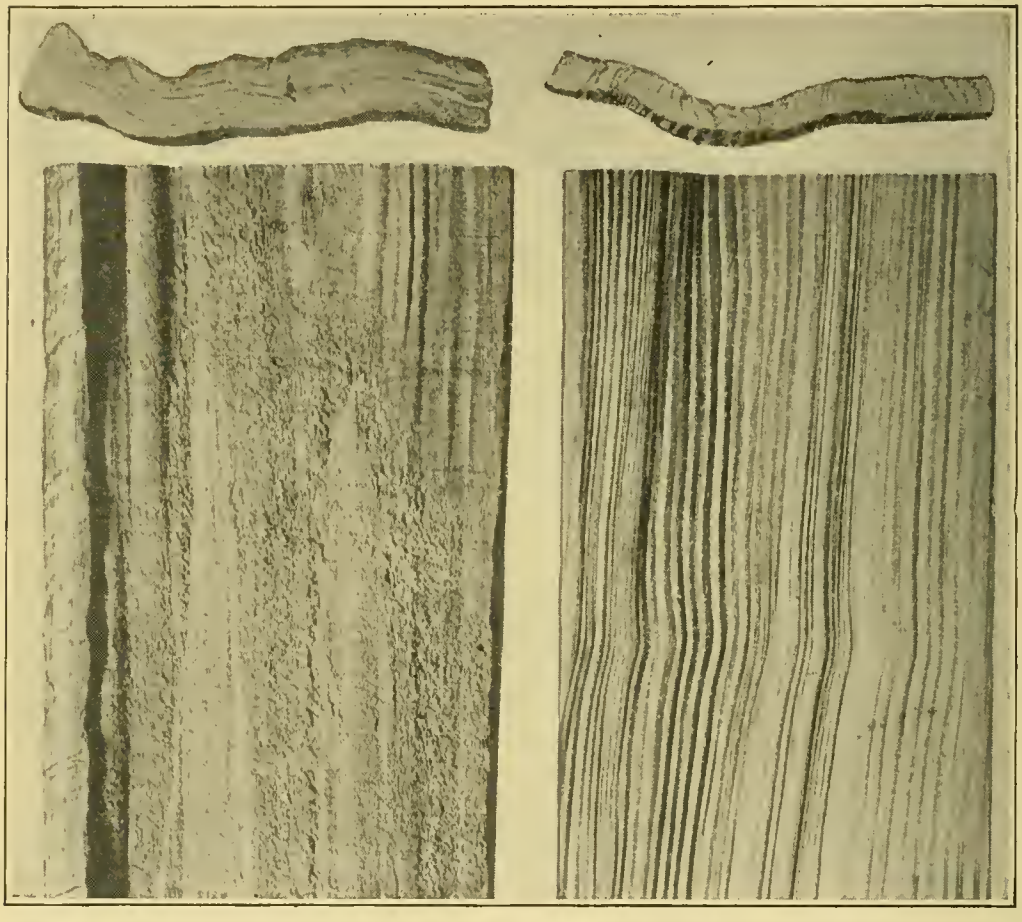


FIG. 36.—Western red cedar board (left) and shingle (right) collapsed in kiln drying. Top pieces are cut off ends.

producing grooves along the surface of the boards, as illustrated in Fig. 36, or a general depression of the sides. These grooves or depressions are not due to an unusual shrinkage of the cell walls, but to a flattening, or caving in, of the cells. This phenomenon has been designated as *collapse*. Its cause may be explained as follows: In very wet wood part of the cells at least are entirely filled with water. As this water leaves the cell cavities, air should take its place but it is very difficult for air to pass through wet cell walls, so, in the absence of air, the cells flatten out similar to what happens if water is drawn out of a rubber tube without admitting air. Figure 37 shows how the cells wrinkle up in western red cedar as it collapses.

It is not the air pressure on the outside of the wood, however, which is responsible for this collapse, as that at most could be but 15 pounds per square inch, but rather the tensile force of the water pulling the wet cell walls together as it leaves. It is well known that this force is much greater than that due to atmospheric pressure.

Collapse takes place in wood principally in kiln drying, since when wet wood becomes hot it also becomes soft and plastic, and under such conditions collapse can take place quite easily. The

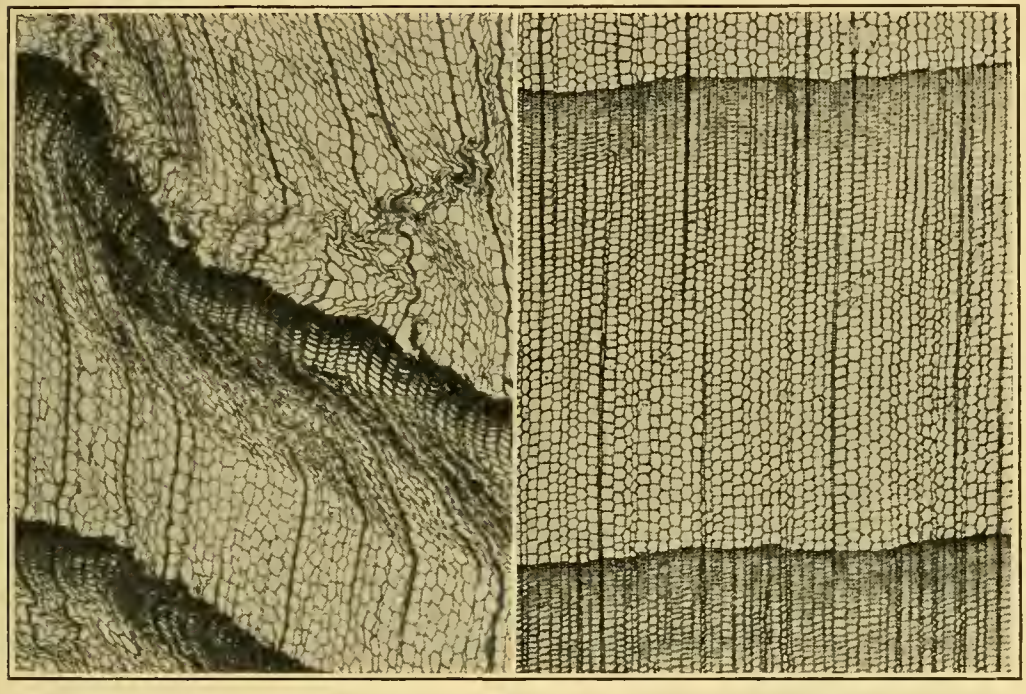


FIG. 37.—Western red cedar with cells collapsed in drying. × 32. Normal western red cedar. × 32. (*Courtesy, Forest Products Laboratory.*)

remedy for collapse, therefore, is to reduce the temperature in the kiln.

If air is already present in the cells, as in partly seasoned lumber or in many green species, collapse does not take place, since the air breaks up the action of the water in drawing the cell walls together as it leaves. Neither does collapse take place at the ends, nor near the surface, nor in the sapwood, as in these places air enters readily. Kiln-dried oak often shows plump sapwood while the adjacent heartwood is shrunken and wrinkled because of uneven collapse of the cells. Collapse, unlike shrinkage, can largely be prevented by careful drying.

2º. **Conductivity of Heat and Electricity.**—Wood conducts heat comparatively slowly. This is one of the principal proper-

ties that makes lumber desirable for building material, furniture, handles, refrigerators, and fireless cookers. A wooden wall allows much less heat to pass through it than an iron, concrete, brick, or stone wall of the same thickness and under the same conditions. Wooden handles do not feel so warm when heated, nor so cold when chilled, as iron or other metal handles having the same temperature, because the heat passes more slowly through the wood to the hand or from the hand to the wood, as the case may be.

The rate of heat conduction must also be taken into consideration in heating wood through preliminary to drying or to impregnating it with preservatives. In such operations, however, the wood may contain a relatively large percentage of moisture, which would facilitate the conduction of heat to the interior. Tests made at the Forest Products Laboratory indicate that 5 to 8 hours are required to heat railway ties to the center when surrounded by saturated steam at 20 to 40 pounds pressure.

The rate at which heat passes through dry wood depends upon the direction of the fibers and upon the density. Wood conducts from two to three times as much heat along the fibers as across the fibers, other conditions being the same.

Dense woods conduct heat more readily than light woods because in light woods a larger volume is occupied by air spaces, and air is a poorer conductor of heat than wood substance (cell walls). Therefore, for fireless cookers, ice cream containers, and other articles requiring good insulation, as light a wood as is practical should be used.

Table VI gives the heat conductivity of various common substances including wood.

Dry wood is a very poor conductor of electricity. For currents of low voltage it is considered a non-conductor. The conductivity increases with increase in moisture content. Light woods are more resistant to the passage of an electric current than dense woods of the same cross-section. Salts injected into timbers for preservative treatment increase the electrical conductivity of the wood. This is a serious handicap in the use of zinc chloride for preserving railway ties since it increases the electric conductivity between the rails or between the rails and the moist ground, thereby interfering with the operation of the block signals.

30. Specific Heat and Thermal Expansion.—The specific heat of a substance is the ratio of the amount of heat required to raise

TABLE VI.—HEAT CONDUCTIVITY OF WOOD AND VARIOUS OTHER MATERIALS AT ORDINARY TEMPERATURES[a]

Substance		Number of calories of heat which pass from one face to the opposite face of 1 cubic centimeter of the material within 1 second of time when the difference in the temperature of the two faces is 1 degree Centigrade
Air		0.00006
Air cell, ½ inch thick		0.000154
Asbestos paper		0.00017
Mill board		0.00029
Concrete, cinder		0.00081
Concrete, stone		0.0022
Corkboard, pure		0.000106
Cotton, firmly packed		0.00010
Flaxlinum, vegetable fibers firm and flexible		0.000113
Glass, window		0.0025
Granite		0.0053
Hair felt		0.000085
Insulite		0.000102
Iron, wrought		0.144
Limestone and marble		0.0047 to 0.0056
Linofelt, vegetable fibers between layers of paper, soft and flexible		0.000103
Pulp board, stiff pasteboard		0.00015
Sand, white dry		0.00093
Sandstone, dry		0.0055
Sawdust		0.00012
Water		0.00136
Wood:	Specific gravity	
Balsa	0.12	0.00012
Boxwood	0.90	0.00036
Cypress	0.46	0.00023
Fir, dry, across fiber		0.00009
Along fiber		0.00030
Greenheart	1.08	0.00112
Gum, red, across fiber (*b*)	0.50	0.00016
Along fiber (*b*)	0.50	0.00044
Lignum-vitae	1.16	0.00060
Mahogany	0.55	0.00031 to 0.00051
Maple, hard	0.71	0.00038
Pine, white	0.50	0.00027
Virginia	0.55	0.00033
Pine, across fiber (*c*)		0.00010
Along fiber (*c*)		0.00030
Oak	0.61	0.00035
Oak	0.65	0.00058
Poplar, yellow	0.58	0.00041
Wool, pure, loosely packed		0.00009

[a] From Smithsonian Physical Tables except (*b*) which are given as "satin walnut" by BARRATT, T., "Thermal Conductivity," *Proceedings Physical Society of London* vol. 27. 1914; and (*c*) which are taken from DUFF'S, A. W., "Textbook of Physics," 1910.

its temperature one degree to the amount of heat required to raise the temperature of an equal weight of water one degree. This varies considerably for different substances as is shown in Table VII. Very few substances have a higher specific heat than water.

It has been shown by Dunlap[1] that the specific heat of wood is practically the same for a large number of species, being approximately 0.327. This is in accordance with chemical analyses which show that the cell walls of all woods are composed of practically the same materials.

TABLE VII.—SPECIFIC HEAT OF WOOD AND VARIOUS OTHER SUBSTANCES[a]

Substance	Specific heat
Air (at constant pressure)	0.2375
Aluminum	0.2226
Copper	0.0917
Granite	0.192
Iron, wrought	0.1152
Limestone	0.216
Marble	0.21
Lead	0.0299
Sandstone	0.22
Water	1.00
Water vapor (at 100° C.)	0.421
Wood, all kinds, dry	0.327

[a] From Smithsonian Physical Tables.

Knowledge of the specific heat of wood is of value in kiln operation, wood preservation, distillation of wood, and all processes in which wood is subjected to changes in temperature. Data on the specific heat of air and water vapor also are important in theoretical considerations of the relative efficiencies of different methods of drying lumber.

All substances, with few exceptions, expand more or less when heated. Table VIII shows the amount per unit length by which various substances may be expected to increase or decrease in heating or cooling 1° F. While different investigators are not in close agreement in their results for the thermal expansion of wood, they agree in that the expansion across the grain is a great deal more than along the grain.

[1] DUNLAP, FREDERICK, "The Specific Heat of Wood." Forest Service *Bull.* **110.**

TABLE VIII.—LINEAR EXPANSION OF WOOD AND VARIOUS OTHER SOLIDS PER UNIT LENGTH PER DEGREE FAHRENHEIT AT ORDINARY TEMPERATURES

Substance	Expansion	
Aluminum	0.0000094	(a)
Brass, cast	0.0000104	
Brick	0.0000031	
Concrete	0.0000080	
Glass, plate and crown	0.0000050	
Granite	0.0000048	
Iron, cast	0.0000059	
Limestone	0.0000014	
Marble	0.0000065	
Porcelain	0.0000017	
Steel, Bessemer hard rolled	0.0000056	
Wood, parallel to fiber:		
Ash	0.0000053	(b)
Beech	0.0000014	
Chestnut	0.0000036	
Elm	0.0000031	
Mahogany	0.0000020	
Maple	0.0000035	
Oak	0.0000027	
Pine	0.0000030	
Walnut	0.0000036	
Yellow birch	0.0000011	(c)
Red oak	0.0000019	
Sugar maple	0.0000012	
Wood, across fiber:		
Beech	0.0000341	(b)
Chestnut	0.0000181	
Elm	0.0000246	
Mahogany	0.0000224	
Maple	0.0000269	
Oak	0.0000302	
Pine	0.0000189	
Walnut	0.0000269	
Yellow birch, tangential	0.0000178	(c)
Radial	0.0000146	
Yellow poplar, tangential	0.0000166	
Radial	0.0000157	
Red oak, tangential	0.0000236	
Red oak, radial	0.0000157	

(a) From MARKS, L. S., "Mechanical Engineer's Handbook." McGraw-Hill Book Co., 1916.

(b) From Smithsonian Physical Tables, 1920.

(c) From unpublished data by MENZEL, C. A. at Forest Products Laboratory.

31. The Sound-producing Qualities of Wood.—When the end of a wooden bar is struck with a hammer or other hard object, a sound of certain pitch is produced. In sticks of the same density the pitch decreases as the length increases, but in sticks of the same length the denser and, therefore, the more elastic the wood the higher the pitch. Wood infected with decay has lost more or less of its elasticity and produces a lower tone when struck. Timber inspectors make use of this principle in determining the quality of timber. A timber with a clear ring and a comparatively high pitch is sound and dense and is considered excellent in quality as far as strength is concerned, provided it contains no weakening defects.

The vibration of wood when struck is turned to advantage in the xylophone, a musical instrument consisting of pieces of wood of various lengths lightly suspended so that when they are struck they will vibrate. The lengths are so graduated that each piece produces a different note. Rosewood is one of the principal woods used for this purpose.

Wood, like other elastic substances, can be set in vibration by sound waves in the air. These induced vibrations intensify the original sound. This property, which is known as *resonance,* is the principle involved in all sounding boards. Wood is preferred to metals for sounding boards because it modifies the notes and does not produce the metallic sound which would be inevitable if metal were used. In other words, the wood modifies the quality but not the pitch of the tone. For this same reason many musical instruments and horns of phonographs are made entirely of wood. The wood used for this purpose must be selected with great care. It must have uniform texture and be free from stresses and all defects and irregularities in grain so that all parts respond alike to the vibrations. Spruce is commonly used for piano and violin sounding boards, organ pipes, and the ribbing of small instruments, as guitars and mandolins. Spruce with narrow rings fairly uniform in width is said to make the best sounding boards. Maple and yellow poplar are also used considerably in various parts of musical instruments because of their uniform texture and good sounding qualities.

Wood does not vibrate so freely as the more elastic metals, and, therefore, is less noisy, a quality which makes it highly preferable for building material, pavements, and furniture. One need only be reminded of the noises emanating from a boiler shop

in order to appreciate the comparative quietness of wooden surroundings.

All materials absorb sound more or less, just as various colored objects absorb light to a greater or less extent instead of reflecting all of it. The unabsorbed sound reverberates back and forth until finally all of it is absorbed. Reverberation in a room hinders the clear understanding of speech. It may be reduced by introducing proper absorbing materials. The relative amounts of sound absorbed by various materials are shown in Table IX, in which it is assumed that an open window absorbs all, or 100 per cent, of the sound that reaches it.

TABLE IX.—COEFFICIENT OF ABSORPTION[a]

Substance	Coefficient
Open window	100
Hair felt (1 inch thick and about 3 inches from wall)	78.0
Audience (per person)	44.0
Carpet rugs	20.0
Wood sheathing (hard pine)	6.1
Plaster and lath	3.4
Plaster on tile	2.5
Brick set in plaster cement	2.5

[a] From DUFF, A. W., "Textbook of Physics," p. 549. P. Blakiston's Son and Company, 1916.

32. Odor and Taste.—Practically all woods, when fresh, and many dry woods, when worked, have more or less of an odor, but in only a few woods is the odor sufficiently pronounced to make it a factor in their utilization. Among our native woods the cedars probably rank first in strength of odor. Port Orford cedar has a spicy resinous odor which is so strong that it cannot be endured continuously by workmen at sawmills where this species is cut. Locally, the Port Orford cedar is known as "ginger pine." In other cedars the odor is less spicy and more aromatic. The red cedar, or juniper, used for lead pencils has a very pleasant aromatic odor.

One of the characteristics of the woods of the laurel family is their spicy odor, which is of aid in their identification, for no other native hardwoods have this odor. In certain sections of the country, bedsteads made of sassafras are preferred because this

wood is said to repel bedbugs. The California laurel, or Oregon myrtle, has a peppery odor and, therefore, is also known as pepperwood. Among foreign woods of the laurel family camphorwood can be easily recognized by its camphor-like odor.

The pines have a resinous odor, more pronounced in the yellow pines than in the white pines. Cypress has a rancid odor which is not strong but can be readily detected if the wood is whittled or sawed and the sawdust held to the nostrils. The odor is stronger in the darker grades of cypress. Fresh hemlock has a distinctly sour odor, but in the dry wood it is not noticeable. The odor of cottonwood is very faint in single pieces, but becomes evident as one enters places where egg cases, cracker boxes, and other containers made of cottonwood are stored. The only native woods with a decidedly disagreeable odor are the sheepberry and nannyberry (*Viburnums*). Usually the odor is more pronounced when the wood is green or remoistened than when it is dry.

The odor of wood adds to its value for some purposes. The cedars (including junipers) are desirable for lining closets, drawers, and chests because of the moth-repelling properties which their odor is supposed to have.[1] A similar use for sassafras has already been mentioned. Spanish cedar (a hardwood not related to native cedars) is used for cigar boxes on account of the pleasant odor it imparts to the contents. Sandalwood is another important foreign wood prized for its odor. It is used for perfumery and incense. It grows in India and the Malay Archipelago.

In woods used for food containers strong odors are objectionable because they may be imparted to the food. However, only a few species need be barred for this reason. The cedars, sassafras, and highly resinous yellow pines probably are the only commercial woods that should not be used for kitchen cabinets, kitchen cupboards, and refrigerators. For butter boxes, wooden plates, bowls, and spoons, or any article in which the food comes in direct contact with the wood, that having a distinct odor should not be used.

Taste is closely related to odor, and most woods with a pronounced odor also have a similar taste, although in cypress, hemlock, and cottonwood the odor is more pronounced than the

[1] Bach, E. A. and Robak, Frank, "Red Cedar Chests as Protection Against Moth Damage." United States Department of Agriculture *Bull.* **1051.**

taste. Taste and odor are more pronounced in the heartwood than in the sapwood. The bitter taste of the heartwood of cedar readily distinguishes it from cypress and redwood. Chestnut wood when chewed has a stringent effect on the mouth because of the tannin contained in the wood. Sugar pine owes its name to the sweet exudations[1] found on wounds of the tree or on lumber. Containers used for liquids for drinking purposes must be made of tasteless woods or otherwise they must be thoroughly leached out before being used. The selection of suitable woods for lead pencils involves their taste, because few pencils pass through their period of usefulness without being held in the mouth more or less.

33. Color.—Among the properties of wood that make it superior to many competing materials, color or variation in color ranks among the foremost. No other common finishing material offers such a multiplicity of shades to choose from. The white of holly, the black of ebony, the chocolate brown of black walnut, the reddish brown of mahogany, and many other natural shades, including green, yellow, and purple together with the adaptability of wood to artificial staining, make possible a variety of decorative effects which lend themselves to the expression of individual tastes. The fact that wood finish is considered highly beautifying in its effect is nowhere better exemplified than in the steel cars of the Pullman Company which are finished on the interior with the facsimile figure and color of wood.

The sapwood of all species is light colored. It may be slightly tinged with the color of the heartwood; for example, the sapwood of red gum is slightly reddish, and that of osage orange is yellowish, but, in general, the sapwood is said to be white in color. The color of the heartwood is due to slight infiltrations of colored substances into the cell walls and, occasionally, also to deposits within the cell cavities.

Some woods contain enough coloring matter to make them valuable for the dyes that may be extracted. The more commonly known dyewoods are logwood and fustic of tropical America. Recently the native osage orange has been used extensively for dyeing textiles and leather. The early settlers used extract from the bark of butternut and the husks of black walnut to

[1] The exudation does not contain a true sugar. The sweet substance is pinite, or manzite, which is a benzene derivative.

dye their homespun; and the red dye used by the Indians is said to have been obtained from the roots of dogwood. Some woods impart color to the water in which they are soaked; for example, redwood and black walnut. Rain water flowing over redwood shingles becomes reddish at first, but after the first few rains the leaching ceases.

Since the coloring matter is confined almost entirely to the heartwood, species with wide sapwood produce two kinds of lumber, the white from the sapwood and the dark from the heartwood. In the manufacture of red cedar chests both heartwood and sapwood are used, thus offsetting the monotony of the figureless heartwood.

Many woods turn darker on exposure to the light and air. This change may take place in a few hours, as in alder, or several years may elapse before a change is noticeable. Old mahogany is always darker than freshly cut material, and this is one reason why new mahogany furniture is stained dark, giving it the appearance of antique mahogany. The so-called "Philippine mahogany" turns lighter in color on exposure. Alpine houses built of wood usually are dark in color. This is due to the intense actinic power of the sun and snows at high altitudes.

Methods of changing the color of wood uniformly throughout have been tried with limited success. Soaking woods in dyes, or forcing the dye in under pressure, often results in uneven penetration, giving the wood a streaked appearance.

Heat darkens wood. At the Forest Products Laboratory woods have been darkened uniformly throughout by steaming them under high temperatures and pressures. The chief difficulty met in this treatment is that many woods check when subjected to temperatures severe enough to change their color. A moderate steam treatment has been found to darken the sapwood of red gum and black walnut so as to make it look more like the heartwood. Oak which has been under water or under ground for a long period of time is darker throughout than freshly cut oak. The wood of the California laurel, or Oregon myrtle, is darkened by leaving the green logs submerged in water for a long time.

Woods which contain considerable tannin, as oak, can be stained a beautiful dull brown by exposing them 1 to 3 days to the action of ammonia fumes. Oak so treated is known as "fumed oak."

All attempts at bleaching wood have so far met with mediocre success. One method of bleaching wood is to expose it to the fumes of sulphur dioxide. Another method, which is patented,[1] consists in treating the wood with an alkaline solution of hydrogen peroxide thickened with sodium silicate, and then adding potassium permanganate in successive portions. Oxalic acid will remove dark spots from wood, but it is not satisfactory as a bleach.

The natural color of wood is, to a certain extent, an indication of its resistance to decay. Dark woods, like black walnut, cherry, red cedar, redwood, and mahogany, are more durable in moist locations than most light-colored woods. There are exceptions, however. Some of the cedars are light colored but are very durable; the red oaks are darker than the white oaks but not nearly so resistant to decay.

Abnormal discoloration often is a sign of advanced decay. Mature basswood trees are commonly darker near the center of the trunk as a result of decay having set in. The sapwood of some species, especially the pines and red gum, is subject to a bluish discoloration known as "sapstain," which lowers the value of the lumber for finishing purposes. The cause and prevention of sap stain will be discussed more fully under Chap. IX.

No attempt will be made here to discuss the staining, painting, or other finishing of wood, since this is a subject large enough for a book in itself. Information along this line can be obtained from numerous publications.[2]

[1] Franck-Philipson, U. S. Patent 1,068,580.

[2] The following are some good publications on wood finishing:

"Paint and Varnish." Bureau of Standards *Circular* **69**. Government Printing Office, Washington, D. C.

"Materials of the Household," pp. 114–129. Bureau of Standards *Circular* **70**. Government Printing Office, Washington, D. C.

Kelly, A. Ashnum, "The Expert Wood Finisher." J. F. Tapley and Company, New York, 1915.

Schmidt, Walter K., "Problems of the Finishing Room." Periodical Publishing Company, Grand Rapids, Michigan, 1916.

Hoff, J. N., "Paints and Varnish Facts and Formulae." D. Van Nostrand Company, New York, 1905.

Sabin, A. H., "House Painting and Technology of Paints and Varnishes." John Wiley and Sons, New York, 1908.

Jennings, A. Seymour, "Commercial Paints and Paintings." D. Van Nostrand Company, New York, 1915.

Gardner, Henry A., "Paint Technology and Tests." McGraw-Hill Book Company, New York, 1911.

CHAPTER IV

THE MECHANICAL PROPERTIES, OR STRENGTH, OF WOOD

The mechanical properties of a material may be defined as those properties which enable it to resist external forces which tend to change its size or shape. A piece of soft putty offers little resistance to forces which tend to deform it and, therefore, it ranks low in strength; a wooden stringer or post, on the other hand, may show great resistance to external forces in which case it is considered strong. Shrinking, warping, and expansion or contraction due to changes in temperature also cause changes in the shape of a piece of wood, but such changes are due to forces acting from within and are not related to its mechanical properties.

Whenever external forces act on a solid body they change its shape more or less and there are induced internal resisting forces which balance the external forces. The change in shape is known as *deformation*, and the internal resisting forces are called *stresses*. As the external forces increase, the deformation and internal stresses also increase. When the internal stresses in any part of a body exceed the force of cohesion between the particles in that part, permanent deformation, or what is known as *failure*, occurs.

The internal stresses produced may be of various kinds, as, compressive stresses, tensile stresses, shearing stresses, bending stresses, and torsion stresses. The maximum stresses that wood will endure depend upon the kind and condition of the wood and whether the stresses act along or across the grain.

The term "strength" as used in the broad sense includes all mechanical properties, but more often it is used in a more limited sense which does not include such properties as stiffness, toughness, cleavability, and hardness. No matter how it is used, the word "strength" does not have a definite meaning unless it is modified, as, cross-breaking strength in static bending, end-crushing strength, tensile strength along the grain, or strength in longitudinal shear.

The mechanical properties of the more common woods have been known in a general way for a long time. It is well known that oak is strong when used as a beam or post, hickory and elm are tough, and gum is difficult to split. Definite figures, however, showing what the average strength of each species is and what variations in strength may occur, were not available until the government made tests on our native woods.

The first series of such tests, which was very limited in number, was made in connection with the Tenth Census Report (1880) under the direction of C. S. Sargent. The Forest Service has since made some tests in cooperation with various state universities, but the most comprehensive series of such tests is being made at the Forest Products Laboratory maintained in cooperation with the University of Wisconsin at Madison. These tests are made mostly on small clear pieces, 2 by 2 inches in cross-section so as to obtain reliable data for comparison, but some tests are also made on larger beams and columns in order to learn the weakening effect of defects of various kinds. In these tests the influence of such factors as the dry weight of the wood, the moisture content, the rate of growth, the position in the tree, and the locality from which the tree came are taken into consideration.

Tables X, XI, XII, and XIV in this chapter represent fair averages of the mechanical properties of native woods, and Table XIII gives the mechanical properties of some other materials for comparison. It must be remembered that the wood of each species, and even of the same tree, varies considerably in strength; therefore, these tables cannot be looked upon as giving absolute values for a given species of wood, but rather an indication of what may be expected if the wood is of average quality. Chapter V contains information helpful in judging whether a certain piece of wood is above or below the average in quality.

To the layman the tables are of value chiefly in comparing one wood with another, but the engineer and architect use them to calculate the size of timbers required to hold certain loads, thus enabling them to build safe structures and at the same time not to use more material than is necessary.

34. Strength in Compression.—The strength of wood in compression is indicated by the resistance it offers to forces which tend to crush it. In timber testing the strength in com-

pression is determined parallel and perpendicular to the grain. Posts in buildings and wagon spokes are subjected to compression along the grain, or end compression, as it is also called, and sills and railway ties are subjected to compression perpendicular to the grain, or side compression. Wood shows relatively high strength in compression along the grain. Comparatively short pieces of clear green wood (excepting the very lightest kinds) will support from 1 to 3 tons per square inch in end compression. Clear pieces of air-seasoned wood (excepting the

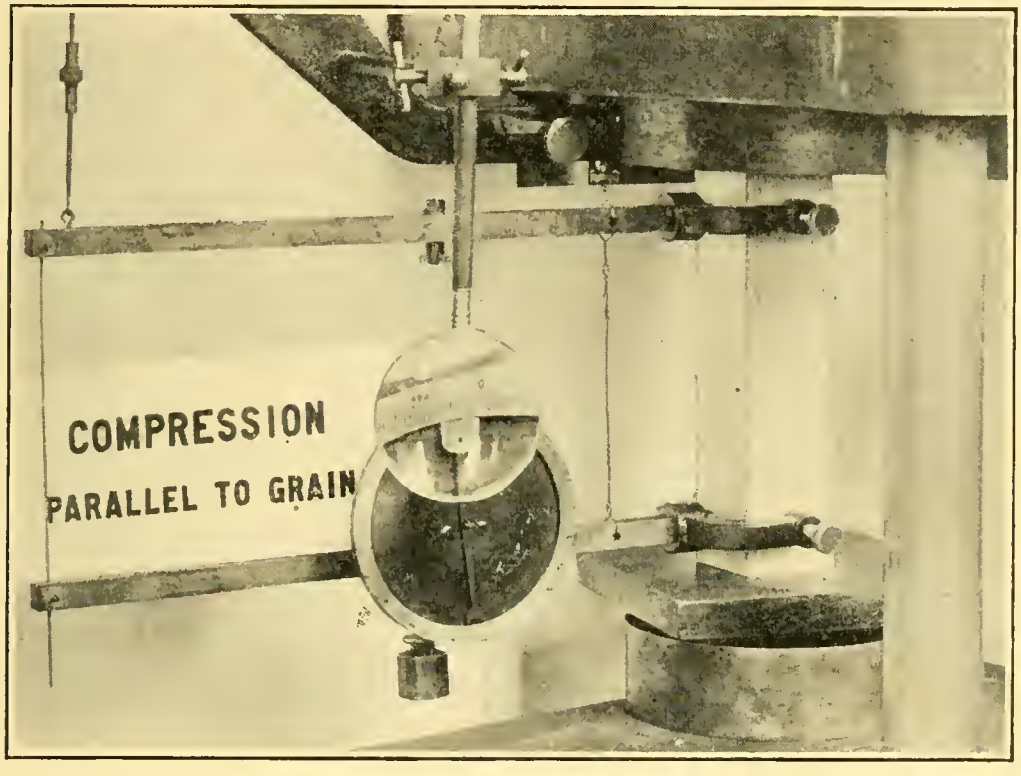


FIG. 38.—Wood specimen 2 by 2 by 8 inches in machine for test in compression parallel to the grain. (*Courtesy, Forest Produets Laboratory.*)

very lightest kinds) will support from 2½ to 7 tons per square inch.

The strength in compression along the grain is determined by placing short specimens (at the Forest Products Laboratory pieces 2 by 2 by 8 inches are used usually) in a testing machine and increasing the load on the ends until the maximum is reached. Figure 38 shows a block of wood which is being tested in end compression. Dividing the load in pounds by the cross-sectional area in inches gives the maximum crushing strength parallel to the grain in pounds per square inch. See Tables X and XI for the compressive strength of clear pieces of wood and Table

TABLE X.—RESULTS OF TESTS ON SMALL CLEAR GREEN PIECES OF WOOD[a]

[Test specimens are 2 by 2 inches in section. Bending specimens are cut 30 inches long; others are shorter, depending on kind of test.]

Common and botanical name	Locality where grown	Moisture content (per cent)	Specific gravity, oven dry, based on—		Weight per cubic foot (green) (pounds)	Static bending				Impact bending, height of drop causing complete failure, 50-pound hammer (inches)	Compression parallel to grain		Compression perpendicular to grain—fiber stress at elastic limit (pounds per square inch)	Shearing strength parallel to grain (pounds per square inch)	Tension perpendicular to grain (pounds per square inch)	Hardness, load required to imbed a 0.444-inch ball to one-half its diameter	
			Volume when green	Volume when oven dry		Fiber stress at elastic limit (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)	Work in bending to maximum load (inch-pounds per cubic inch)		Fiber stress at elastic limit (pounds per square inch)	Maximum crushing strength (pounds per square inch)				End (pounds)	Side (pounds)
1	2	3	4	4a	5	6	7	8	9	10	11	12	13	14	15	16	17
Hardwoods																	
Alder, red (*Alnus oregona*).....	Washington.....	98	0.37	0.43	46	3,800	6,500	1,170	8.0	22	2,650	2,960	310	770	390	550	440
Ash, black (*Fraxinus nigra*).....	Michigan, Wisconsin.	83	.46	.53	53	2,600	6,000	1,020	12.4	32	1,620	2,290	430	870	490	580	550
Ash, white (forest grown) (*Fraxinus americana*).	Arkansas, West Virginia.	43	.52	.60	46	4,900	9,100	1,350	13.4	36	3,230	3,800	800	1,260	620	1,000	900
Ash, white (second growth) (*Fraxinus americana*).	New York.	40	.58	.71	51	6,100	10,800	1,640	16.3	47	3,820	4,610	790	1,600	790	1,140	1,080
Aspen (*Populus tremuloides*).....	Wisconsin.	107	.36	.42	47	2,900	5,300	840	6.9	28	1,620	2,160	200	620	180	270	320
Basswood (*Tilia americana*).....	Pennsylvania, Wisconsin.	103	.33	.40	41	2,700	5,000	1,030	5.2	17	1,710	2,210	210	610	280	280	250
Beech (*Fagus atropunicea*).....	Indiana, Pennsylvania.	62	.54	.66	55	4,500	8,200	1,240	12.5	40	2,550	3,280	610	1,210	760	950	820

Birch, paper (*Betula papyrifera*).	Wisconsin.	72	.47	.60	51	2,900	5,800	1,010	15.0	45	1,650	2,210	300	790	380	400	490
Birch, sweet (*Betula lenta*).....	Pennsylvania.	61	.59	.70	59	4,500	8,600	1,490	15.6	44	2,650	3,560	520	1,220	550	1,020	890
Birch, yellow (*Betula lutea*).....	Pennsylvania, Wisconsin.	68	.54	.66	58	4,600	8,600	1,540	16.6	40	2,760	3,460	450	1,110	480	820	740
Buckeye, yellow (*Æsculus octandra*).....	Tennessee.	141	.33	.38	49	2,600	4,800	980	5.4	18	1,640	2,050	210	660	320	360	290
Butternut (*Juglans cinerea*).....	Tennessee, Wisconsin.	104	.36	.40	46	2,900	5,400	970	8.2	24	1,960	2,420	270	760	430	410	390
Cherry, black (*Prunus serotina*)..	Pennsylvania.	55	.47	.53	46	4,200	8,000	1,310	12.8	33	2,940	3,540	440	1,130	570	750	660
Chestnut (*Castanea dentata*).....	Maryland, Tennessee.	122	.40	.46	55	3,100	5,600	930	7.0	24	2,040	2,470	380	800	430	530	420
Cottonwood (*Populus deltoides*)..	Missouri.	111	.37	.43	49	2,900	5,300	1,010	7.3	21	1,770	2,280	240	680	410	380	340
Cucumber tree (*Magnolia acuminata*).....	Tennessee.	80	.44	.52	50	4,200	7,400	1,560	10.0	30	2,760	3,140	410	990	440	600	520
Dogwood (flowering) (*Cornus florida*).....	Tennessee.	62	.64	.80	65	4,800	8,800	1,180	21.0	58	.....	3,640	1,030	1,520	.....	1,410	1,410
Elm, cork (*Ulmus racemosa*)....	Wisconsin.	50	.58	.66	54	4,600	9,500	1,190	19.8	50	2,870	3,780	750	1,270	660	980	990
Slippery (*Ulmus pubescens*)....	Indiana, Wisconsin.	85	.48	.56	56	4,000	8,000	1,230	15.4	47	2,840	3,320	510	1,110	650	750	660
White (*Ulmus americana*).....	Wisconsin, Pennsylvania.	88	.44	.54	52	3,600	6,900	1,030	11.0	34	2,290	2,880	390	920	560	610	550
Gum, black (*Nyssa sylvatica*)....	Tennessee.	55	.46	.55	45	4,000	7,000	1,030	8.0	30	2,440	3,040	600	1,100	570	790	640
Cotton (*Nyssa aquatica*).....	Louisiana.	97	.46	.52	56	4,200	7,300	1,050	8.3	30	2,760	3,370	590	1,190	600	800	710
Red (*Liquidambar styraciflua*).	Missouri.	81	.44	.53	50	3,700	6,800	1,150	9.4	33	2,360	2,840	460	1,070	510	630	520
Hackberry (*Celtis occidentalis*)...	Indiana, Wisconsin.	65	.48	.56	50	2,900	6,500	950	14.5	48	2,060	2,650	490	1,070	630	760	690
Hickory, big shellbark (*Hicoria laciniosa*).....	Mississippi, Ohio.	61	.62	....	63	5,600	10,500	1,340	29.9	104	2,740	3,920	1,000	1,190	.....	.....	.....
Bitternut (*Hicoria minima*)...	Ohio.	66	.60	....	63	5,500	10,300	1,400	20.0	66	4,330	4,570	990	1,240	.....	.....	.....
Mockernut (*Hicoria alba*).....	West Virginia, Mississippi, Pennsylvania.	59	.64	....	64	6,300	11,100	1,570	26.1	88	3,900	4,480	1,000	1,280	.....	.....	.....
Pecan (*Hicoria pecan*).....	Missouri.	63	.60	.69	61	5,200	9,800	1,370	14.6	53	3,040	3,990	960	1,480	680	1,270	1,310
Pignut (*Hicoria glabra*).....	Ohio, Mississippi, Pennsylvania, West Virginia.	54	.66	....	64	6,200	11,700	1,650	31.7	89	3,950	4,810	1,140	1,370	.....	.....	.....
Shagbark (*Hicoria ovata*).....	Ohio, Mississippi, Pennsylvania, West Virginia.	60	.64	....	64	5,900	11,000	1,570	23.7	74	3,430	4,580	1,000	1,320	.....	.....	.....
Holly, American (*Ilex opaca*)....	Tennessee.	82	.50	.61	57	3,400	6,500	900	10.8	51	1,970	2,640	610	1,130	610	860	790
Hornbeam (*Ostrya virginiana*)...	Wisconsin.	52	.63	.76	60	4,500	8,500	1,150	13.3	73	2,620	3,570	730	1,370	450	1,160	1,170
Laurel, California (*Umbellularia californica*).....	Oregon.	70	.51	.59	55	3,900	6,600	720	16.8	57	1,960	3,020	800	1,270	780	1,020	1,000
Mountain (*Kalmia latifolia*)...	Tennessee.	62	.62	.74	62	5,800	8,400	920	12.5	32	.....	4,310	1,110	1,670	....	1,400	1,300
Locust, black (*Robinia pseudacacia*).....	Tennessee.	40	.66	.71	58	8,800	13,800	1,850	15.4	44	6,280	6,800	1,430	1,760	770	1,640	1,570

TABLE X.—RESULTS OF TESTS ON SMALL CLEAR GREEN PIECES OF WOOD[a]—*Continued*

Common and botanical name	Locality where grown	Moisture content (per cent)	Specific gravity, oven dry, based on—		Weight per cubic foot (green) (pounds)	Static bending				Impact bending, height of drop causing complete failure, 50-pound hammer (inches)	Compression parallel to grain		Compression perpendicular to grain—fiber stress at elastic limit (pounds per square inch)	Shearing strength parallel to grain (pounds per square inch)	Tension perpendicular to grain (pounds per square inch)	Hardness, load required to imbed a 0.444-inch ball to one-half its diameter	
			Volume when green	Volume when oven dry		Fiber stress at elastic limit (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)	Work in bending to maximum load (inch-pounds per cubic inch)		Fiber stress at elastic limit (pounds per square inch)	Maximum crushing strength (pounds per square inch)				End (pounds)	Side (pounds)
1	2	3	4	4a	5	6	7	8	9	10	11	12	13	14	15	16	17
Hardwoods—Cont'd.																	
Locust, honey (*Gleditsia triacanthos*)	Missouri, Indiana	63	0.60	0.67	61	5,600	10,200	1,290	12.6	47	3,320	4,420	1,420	1,660	930	1,440	1,390
Magnolia (evergreen) (*Magnolia foetida*)	Louisiana.	117	.46	.53	62	3,600	6,800	1,110	15.4	54	2,200	2,700	570	1,040	610	780	740
Maple, Oregon (*Acer macrophyllum*)	Washington.	72	.44	.51	47	4,400	7,400	1,100	8.7	23	2,380	3,240	550	1,110	600	760	620
Red (*Acer rubrum*)	Pennsylvania, Wisconsin.	70	.48	.54	51	4,100	7,800	1,420	10.6	30	2,500	3,350	520	1,080	580	740	600
Silver (*Acer saccharinum*)	Wisconsin.	66	.44	.51	46	3,100	5,800	940	11.0	29	1,950	2,490	460	1,050	560	670	590
Sugar (*Acer saccharum*)	Indiana, Pennsylvania, Wisconsin.	60	.56	.66	56	5,000	9,100	1,480	11.9	36	3,120	3,860	750	1,380	770	1,000	910
Oak, bur (*Quercus macrocarpa*)	Wisconsin.	70	.58	.67	61	3,600	7,200	880	10.7	44	2,310	3,290	840	1,350	800	1,160	1,110
California black (*Quercus californica*)	California, Oregon	106	.51	.58	66	3,400	6,200	740	8.8	30	1,880	2,800	890	1,140	700	910	850

Oak, canyon live (*Quercus chrysolepsis*)	California.	62	.70	.84	71	6,300	10,600	1,340	14.4	47	4,050	4,690	1,480	1,700	970	1,590	1,570
Chestnut (*Quercus prinus*)	Tennessee.	72	.57	.67	62	4,600	8,000	1,370	9.4	35	2,890	3,520	660	1,210	690	970	890
Cow (*Quercus michauxii*)	Louisiana.	76	.60	.76	65	4,800	8,500	1,350	12.8	45	3,060	3,540	710	1,260	670	1,100	1,110
Laurel (*Quercus laurifolia*)	Louisiana.	84	.56	.70	64	4,500	7,900	1,390	11.2	39	2,730	3,170	710	1,180	770	1,020	1,000
Pacific post (*Quercus garryana*)	Oregon.	72	.64	.75	69	4,600	7,700	790	13.7	49	2,510	3,570	1,380	1,630	940	1,430	1,390
Post (*Quercus minor*)	Arkansas, Louisiana.	69	.60	.74	63	5,000	8,100	1,090	11.0	44	2,840	3,480	1,060	1,280	790	1,160	1,130
Red (*Quercus rubra*)	Arkansas, Louisiana, Indiana, Tennessee.	84	.56	.65	64	3,700	7,700	1,290	11.5	41	2,330	3,200	730	1,120	740	1,020	950
Spanish (highland) (*Quercus digitota*)	Louisiana.	90	.52	.62	62	4,200	6,900	1,140	8.0	29	2,180	3,030	680	930	480	910	860
Spanish (lowland) (*Quercus pagodæfolia*)	Louisiana.	78	.61	.71	67	6,500	10,800	1,790	14.7	54	3,760	4,620	940	1,320	800	1,270	1,240
Water (*Quercus nigra*)	Louisiana.	81	.56	.68	63	5,600	8,900	1,550	11.1	39	3,200	3,740	770	1,240	820	1,050	1,010
White (*Quercus alba*)	Arkansas, Louisiana, Indiana.	68	.60	.71	62	4,700	8,300	1,250	11.5	42	2,990	3,560	830	1,250	770	1,120	1,060
Willow (*Quercus phellos*)	Louisiana.	94	.56	.69	67	4,400	7,400	1,290	8.8	35	2,480	3,000	750	1,180	760	1,020	980
Yellow (*Quercus velutina*)	Arkansas, Wisconsin.	78	.56	.67	63	4,600	8,200	1,180	12.3	40	2,870	3,460	870	1,180	830	1,000	1,060
Persimmon (*Diospyros virginiana*)	Missouri.	58	.64	.78	63	5,600	10,000	1,370	13.0	41	3,030	4,170	1,110	1,470	770	1,240	1,280
Poplar, yellow (*Liriodendron tulipifera*)	Tennessee	64	.37	.42	38	3,200	5,600	1,210	5.6	17	2,000	2,550	310	790	460	420	340
Sassafras (*Sassafras sassafras*)	Tennessee.	67	.42	.47	44	3,600	6,000	910	7.1	37	2,410	2,730	460	950	520	610	520
Sycamore (*Platanus occidentalis*)	Indiana, Tennessee.	83	.46	.54	52	3,300	6,500	1,060	7.5	26	2,390	2,920	450	1,000	630	700	610
Walnut, black (*Juglans nigra*)	Kentucky.	81	.51	.56	58	5,400	9,500	1,420	14.6	37	3,600	4,300	600	1,220	570	960	900
Willow, black (*Salix nigra*)	Wisconsin, Missouri.	138	.34	.41	50	1,800	3,800	560	10.8	35	970	1,510	210	620	430	350	360
Conifers.																	
Cedar, incense (*Libocedrus decurrens*)	California, Oregon.	108	.35	.36	45	3,900	6,200	840	6.4	17	2,870	3,150	460	830	280	570	390
Port Orford (*Chamæcyparis lawsoniana*)	Oregon.	52	.41	.47	39	3,900	6,800	1,500	7.8	25	2,970	3,280	380	880	240	560	480
Western red (*Thuja plicata*)	Washington, Montana.	39	.31	.34	27	3,300	5,200	950	5.0	17	2,500	2,840	310	720	210	430	260
White (*Thuja occidentalis*)	Wisconsin.	55	.29	.32	28	2,600	4,200	640	5.7	15	1,420	1,990	290	620	240	320	230
Cypress, bald (*Taxodium distichum*)	Louisiana, Missouri.	87	.41	.47	48	4,000	6,800	1,190	6.4	24	3,100	3,490	470	820	280	470	380
Douglas fir (*Pseudotsuga taxifolia*)	Washington, Oregon.	36	.45	.52	38	5,000	7,800	1,580	6.7	25	3,400	3,940	530	910	200	510	470
Douglas fir (*Pseudotsuga taxifolia*)	Montana, Wyoming.	38	.40	.44	34	3,600	6,400	1,180	6.8	20	2,520	3,000	450	880	350	450	400

TABLE X.—RESULTS OF TESTS ON SMALL CLEAR GREEN PIECES OF WOOD[a]—*Continued*

Common and botanical name	Locality where grown	Moisture content (per cent)	Specific gravity, oven dry, based on— Volume when green	Volume when oven dry	Weight per cubic foot (green) (pounds)	Static bending: Fiber stress at elastic limit (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)	Work in bending to maximum load (inch-pounds per cubic inch)	Impact bending, height of drop causing complete failure, 50-pound hammer (inches)	Compression parallel to grain: Fiber stress at elastic limit (pounds per square inch)	Maximum crushing strength (pounds per square inch)	Compression perpendicular to grain—fiber stress at elastic limit (pounds per square inch)	Shearing strength parallel to grain (pounds per square inch)	Tension perpendicular to grain (pounds per square inch)	Hardness, load required to imbed a 0.444-inch ball to one-half its diameter: End (pounds)	Side (pounds)
1	2	3	4	4a	5	6	7	8	9	10	11	12	13	14	15	16	17
Conifers—Cont'd.																	
Fir, amabilis (*Abies amabilis*)	Oregon, Washington.	102	0.37	0.42	47	3,900	6,300	1,300	6.0	21	2,380	2,930	320	670	240	360	310
Balsam (*Abies balsamea*)	Wisconsin.	117	.34	.41	45	3,000	4,900	960	4.7	16	2,220	2,400	210	610	180	290	290
Grand (*Abies grandis*)	Montana, Oregon	94	.37	.42	44	3,600	6,100	1,300	5.6	22	2,680	3,010	340	760	230	420	360
Noble (*Abies nobilis*)	Oregon.	41	.35	.41	31	3,400	5,700	1,280	6.2	20	2,370	2,700	310	700	180	300	250
White (*Abies concolor*)	California.	156	.35	.44	56	3,900	6,000	1,130	5.2	18	2,610	2,800	440	730	260	380	330
Hemlock (eastern) (*Tsuga canadensis*)	Tennessee, Wisconsin.	105	.38	.44	48	4,200	6,700	1,120	6.8	20	2,710	3,270	500	880	260	510	410
(Western) (*Tsuga heterophylla*)	Washington.	71	.38	.43	41	3,400	6,100	1,190	6.0	20	2,290	2,890	350	810	260	540	430
Larch, western (*Larix occidentalis*)	Montana, Washington.	58	.48	.59	48	4,600	7,500	1,350	7.1	24	3,250	3,800	560	920	230	470	450
Pine, jack (*Pinus divaricata*)	Wisconsin.	105	.39	.46	50	3,000	5,400	920	5.9	30	2,250	2,580	380	760	310	380	370

Pine, Loblolly (*Pinus tæda*)	Florida, North Carolina, South Carolina.	70	.50	.59	54	4,400	7,500	1,380	8.0	32	2,870	3,580	550	900	280	400	450
Lodgepole (*Pinus contorta*)	Colorado, Montana, Wyoming.	65	.38	.44	39	3,000	5,500	1,080	5.6	20	2,100	2,610	310	690	220	320	330
Longleaf (*Pinus palustris*)	Florida, Louisiana, Mississippi.	47	.55	.64	50	5,400	8,700	1,630	8.0	34	3,840	4,390	600	1,070	290	550	590
Norway (*Pinus resinosa*)	Wisconsin.	54	.44	.51	42	3,700	6,400	1,380	5.8	28	2,470	3,080	360	780	190	360	340
Shortleaf (*Pinus echinata*)	Arkansas, Louisiana.	64	.50	.58	50	4,500	8,000	1,450	8.7	39	3,650	3,810	480	890	330	490	560
Slash (*Pinus caribaea*)	Florida.	47	.58	.68	53	5,600	8,800	1,630	7.9	37	3,950	4,470	590	1,030	290	570	630
Sugar (*Pinus lambertiana*)	California.	123	.36	.39	50	3,300	5,300	970	5.0	17	2,340	2,600	350	710	270	330	320
Western white (*Pinus monticola*)	Montana.	58	.39	.45	39	3,500	5,700	1,330	5.1	23	2,770	3,070	300	710	250	330	330
Western yellow (*Pinus ponderosa*).	Colorado, Montana, Arizona, Washington, California.	95	.38	.42	46	3,100	5,200	1,010	5.1	19	2,080	2,460	340	680	280	310	320
White (*Pinus strobus*)	Wisconsin.	74	.36	.39	39	3,400	5,300	1,070	5.9	18	2,370	2,720	310	640	260	300	300
Spruce, Engelmann (*Picea engelmanni*)	Colorado.	100	.31	.35	38	2,500	4,200	830	4.9	14	1,740	1,980	290	590	....	250	240
Red (*Picea rubens*)	New Hampshire, Tennessee.	43	.38	.41	34	3,400	5,700	1,180	6.1	18	2,360	2,740	350	770	220	420	350
Sitka (*Picea sitchensis*)	Washington.	53	.34	.37	33	3,000	5,500	1,180	6.4	29	2,280	2,600	330	780	230	430	370
White (*Picea canadensis*)	New Hampshire, Wisconsin.	46	.36	.43	33	3,300	5,400	980	5.7	20	2,280	2,380	270	670	200	300	280
Tamarack (*Larix laricina*)	Wisconsin.	52	.49	.56	47	4,200	7,200	1,240	7.2	28	3,010	3,480	480	860	260	400	380
Yew, western (*Taxus brevifolia*)	Washington.	44	.60	.67	54	6,500	10,100	990	20.2	38	3,400	4,600	1,040	1,620	450	1,340	1,150

[a] From NEWLIN, J. A. and WILSON, T. R. C., "Mechanical Properties of Woods Grown in the United States." United States Department of Agriculture *Bull.* **556.**

Table X is more reliable than Table XI because it is based on a much larger number of tests, and on tests which are not influenced by moisture content because all pieces were above the fiber-saturation point when tested.

The values in this table are averages of a limited number of tests. Considerable variations from these values may occur on account of variations in the density of the wood of any one species. Defects are not considered in this table.

TABLE XI.—RESULTS OF TESTS ON SMALL CLEAR AIR-DRY PIECES OF WOOD[a]

[Test specimens are 2 by 2 inches in section. Bending specimens are cut 30 inches long; others are shorter, depending on kind of test.]

Common and botanical name	Locality where grown	Moisture content (per cent)	Specific gravity, oven dry, based on volume when air dry	Weight per cubic foot (air dry) (pounds)	Static bending				Impact bending, height of drop causing complete failure, 50-pound hammer (inches)	Compression parallel to grain		Compression perpendicular to grain—fiber stress at elastic limit (pounds per square inch)	Shearing strength parallel to grain (pounds per square inch)	Tension perpendicular to grain (pounds per square inch)	Hardness, load required to imbed a 0.444-inch ball to one-half its diameter	
					Fiber stress at elastic limit (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)	Work in bending to maximum load (inch-pounds per cubic inch)		Fiber stress at elastic limit (pounds per square inch)	Maximum crushing strength (pounds per square inch)				End (pounds)	Side (pounds)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Hardwoods																
Alder, red (*Alnus oregona*)	Washington.	8.6	0.42	29	8,100	10,800	1,440	8.5	20	5,350	7,050	650	1,210	430	1,170	650
Ash, black (*Fraxinus nigra*)	Michigan, Wisconsin.	10.4	.50	34	8,300	13,900	1,680	15.5	36	5,070	6,890	1,080	1,730	730	1,250	890
White (forest grown) (*Fraxinus americana*)	Arkansas, West Virginia.	8.7	.58	40	10,200	16,800	1,810	15.1	36	5,600	8,190	1,540	2,110	880	1,950	1,320
White (second growth) (*Fraxinus americana*)	New York.	9.5	.64	44	13,000	18,600	1,980	17.0	46	8,500	9,420	2,090	2,520	1,130	2,240	1,680
Aspen (*Populus tremuloides*)	Wisconsin.	5.2	.42	28	7,600	10,800	1,290	7.3	24	4,490	6,400	550	890	380	850	420
Basswood (*Tilia americana*)	Pennsylvania, Wisconsin.	8.4	.38	26	7,300	10,200	1,580	8.1	16	4,430	5,980	580	1,240	370	590	450
Beech (*Fagus atropunicea*)	Indiana, Pennsylvania	11.2	.63	44	9,000	15,000	1,680	13.7	35	4,870	7,400	1,340	1,970	890	1,400	1,190
Birch, paper (*Betula papyrifera*)	Wisconsin.	4.2	58	38	11,400	16,000	1,810	13.2	24	6,780	9,470	910	1,630	.....	1,490	1,280
Sweet (*Betula lenta*)	Pennsylvania.	9.0	.66	45	13,300	19,600	2,140	17.0	48	7,220	10,680	1,750	2,680	610	2,090	1,490
Yellow (*Betula lutea*)	Pennsylvania, Wisconsin.	9.6	.63	44	12,300	18,900	2,200	20.2	58	7,720	9,760	1,410	1,880	890	1,590	1,320

Buckeye, yellow (*Æsculus octandra*)	Tennessee.	6.2	.38	25	7,000	9,300	1,280	6.2	14	4,220	5,870	640	1,140	660	550	400
Butternut (*Juglans cinerea*)	Tennessee, Wisconsin.	7.6	.39	26	7,300	9,300	1,260	8.2	24	4,490	6,680	760	1,360	440	650	530
Cherry, black (*Prunus serotina*)	Pennsylvania.	9.2	.51	35	11,000	13,800	1,540	11.0	28	7,330	8,370	1,020	1,930	560	1,690	1,030
Chestnut (*Castanea dentata*)	Maryland, Tennessee.	8.6	.44	30	7,400	9,700	1,330	6.4	18	4,420	6,620	930	1,160	470	780	580
Cottonwood (*Populus deltoides*)	Missouri.	4.7	.43	28	8,600	11,400	1,640	7.4	19	5,060	7,830	730	1,120	700	740	480
Cucumber tree (*Magnolia acuminata*)	Tennessee.	6.8	.50	33	10,700	15,400	1,940	13.4	37	6,020	8,540	860	1,530	815	1,160	790
Dogwood (flowering) (*Cornus florida*)	Tennessee.	7.5	.77	52	11,800	18,300	1,700	18.9	40	6,030	7,090	2,470	2,740	1,730	2,980	2,530
Elm, cork (*Ulmus racemosa*)	Wisconsin.	8.5	.66	44	9,400	16,500	1,610	18.7	53	5,510	8,420	1,860	2,140	740	1,730	1,470
Slippery (*Ulmus pubescens*)	Indiana, Wisconsin.	8.3	.54	37	9,400	14,900	1,570	17.3	45	5,370	7,800	1,240	1,810	490	1,220	900
White (*Ulmus americana*)	Wisconsin, Pennsylvania.	8.8	.51	35	9,200	14,600	1,490	13.7	44	5,270	6,850	850	1,740	610	1,240	870
Gum, black (*Nyssa sylvatica*)	Tennessee.	7.2	.52	35	9,200	10,900	1,270	5.6	19	4,060	7,000	1,500	1,460	470	1,380	850
Cotton (*Nyssa aquatica*)	Louisiana.	6.1	0.52	34	9,800	11,300	1,370	6.4	20	5,450	7,910	1,530	1,840	940	1,470	990
Red (*Liquidambar styraciflua*)	Missouri.	11.3	.49	31	8,400	12,300	1,500	11.8	32	4,960	6,020	790	1,750	870	1,010	720
Hackberry (*Celtis occidentalis*)	Indiana, Wisconsin.	9.2	.54	37	6,900	12,300	1,250	12.4	42	4,200	6,450	1,330	1,790	570	1,210	930
Hickory, big shellbark (*Hicoria laciniosa*)	Mississippi, Ohio.	8.7	.71	48	9,800	20,500	2,040	22.4	84	.....	9,710	2,660	2,430			
Bitternut (*Hicoria minima*)	Ohio.	9.2	.68	46	10,300	18,800	1,880	17.9	66	.....	10,600	2,390	2,050			
Mockernut (*Hicoria alba*)	Mississippi, Pennsylvania.	8.9	.75	50	13,500	21,600	2,380	22.0	74	.....	10,610	2,540	1,900			
Pecan (*Hicoria pecan*)	Missouri.	6.2	.70	46	12,000	16,200	1,940	13.4	41	6,170	10,890	3,350	2,540	1,310	2,370	2,140
Pignut (*Hicoria glabra*)	Ohio, Mississippi, Pennsylvania, West Virginia.	9.6	.78	53	12,700	22,500	2,410	30.2	70	.....	10,640	2,860	2,450			
Shagbark (*Hicoria ovata*)	Ohio, Mississippi, Pennsylvania, West Virginia.	9.4	.74	50	11,900	22,600	2,290	26.3	65	.....	10,700	2,470	2,340			
Holly, American (*Ilex opaca*)	Tennessee.	6.4	.60	40	8,000	12,700	1,230	10.6	27	4,450	7,820	1,520	2,060	740	1,770	1,150
Hornbeam (*Ostrya virginiana*)	Wisconsin.	5.6	.75	49	13,900	18,600	2,110	14.4	40	8,310	11,750	2,300	2,110	.....	3,150	2,390
Laurel, California (*Umbellularia californica*)	Oregon.	4.9	.58	38	6,700	9,000	1,110	5.2	22	5,220	8,140	1,930	2,340	950	1,980	1,460
Mountain (*Kalmia latifolia*)	Tennessee.	5.0	.72	47	10,900	13,200	1,410	9.1	46	5,270	7,120	2,420	.....	.....	2,670	2,180
Locust, black (*Robinia pseudacacia*)	Tennessee.	10.0	.70	48	13,800	20,700	2,090	19.1	59	7,790	10,880	2,520	2,710	620	1,570	1,730
Honey (*Gleditsia triacanthos*)	Missouri.	6.0	.63	42	10,700	16,700	1,690	12.6	45	6,520	9,520	2,800	2,580	820	2,030	1,600
Magnolia (evergreen) (*Magnolia foetida*)	Louisiana.	8.8	.51	35	7,800	12,500	1,480	12.3	25	3,940	6,600	1,250	1,700	780	1,480	1,120
Maple, Oregon (*Acer macrophyllum*)	Washington.	8.3	.50	34	7,600	12,000	1,580	7.6	30	6,370	7,180	1,120	2,010	520	1,630	950
Red (*Acer rubrum*)	Pennsylvania, Wisconsin.	10.1	.54	37	9,200	14,200	1,740	12.8	31	5,430	7,330	1,280	1,970	660	1,530	990

TABLE XI.—RESULTS OF TESTS ON SMALL CLEAR AIR-DRY PIECES OF WOOD[a]—*Continued*

Common and botanical name	Locality where grown	Moisture content (per cent)	Specific gravity, oven dry, based on volume when air dry	Weight per cubic foot (air dry) (pounds)	Static bending				Impact bending, height of drop causing complete failure, 50-pound hammer (inches)	Compression parallel to grain		Compression perpendicular to grain—fiber stress at elastic limit (pounds per square inch)	Shearing strength parallel to grain (pounds per square inch)	Tension perpendicular to grain (pounds per square inch)	Hardness, load required to imbed a 0.444-inch ball to one-half its diameter	
					Fiber stress at elastic limit (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)	Work in bending to maximum load (inch-pounds per cubic inch)		Fiber stress at elastic limit (pounds per square inch)	Maximum crushing strength (pounds per square inch)				End (pounds)	Side (pounds)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Maple, silver (*Acer saccharinum*)	Wisconsin.	8.2	0.48	32	7,700	10,100	1,210	7.6	24	5,600	6,600	1,180	1,710	490	1,380	750
Sugar (*Acer saccharum*)	Indiana, Pennsylvania, Wisconsin.	10.5	.62	43	10,400	15,800	1,820	13.6	33	6,060	8,570	1,620	2,450	770	2,000	1,430
Oak, bur (*Quercus macrocarpa*)	Wisconsin.	10.2	.65	45	7,000	10,900	1,060	9.6	27	3,700	6,640	1,670	1,920	650	1,460	1,420
California black (*Quercus californica*)	California, Oregon.	5.2	.60	40	8,400	10,500	1,160	5.7	12	4,440	8,420	1,860	1,710	830	1,360	1,280
Canyon live (*Quercus chrysolepsis*)	California.	5.0	.82	54	11,900	14,700	1,810	7.8	32	8,100	13,360	2,890	2,740	1,500	3,360	3,150
Chestnut (*Quercus prinus*)	Tennessee.	9.5	.68	46	10,600	15,000	1,640	11.5	42	5,280	7,840	1,180	1,600	1,510	1,340	1,200
Cow (*Quercus michauxii*)	Louisiana.	11.3	.68	47	7,500	14,500	1,810	11.9	41	4,420	7,580	1,420	2,190	700	1,310	1,260
Laurel (*Quercus laurifolia*)	Louisiana.	9.5	.64	44	8,700	14,000	1,770	12.0	39	5,280	8,230	1,490	2,030	790	1,280	1,260
Pacific post (*Quercus garryana*)	Oregon.	6.6	.76	51	7,800	11,700	1,270	8.5	23	5,020	8,570	2,560	2,210	810	2,090	1,780
Post (*Quercus minor*)	Arkansas, Louisiana.	11.2	.68	47	7,800	13,600	1,540	13.3	46	3,960	6,890	1,900	1,900	780	1,360	1,390
Red (*Quercus rubra*)	Arkansas, Louisiana, Indiana, Tennessee.	10.9	.63	44	8,600	14,200	1,870	13.3	39	4,610	7,370	1,210	1,760	780	1,500	1,310
Spanish (highland) (*Quercus digitata*)	Louisiana.	10.1	.60	41	6,400	11,800	1,560	9.7	26	3,030	6,800	1,180	1,530	520	1,050	1,100

Oak, Spanish (lowland) (*Quercus pagodæfolia*)	Louisiana.	10.0	.69	47	12,000	19,400	2,360	18.8	49	7,010	9,720	1,730	2,170	860	1,640	1,540
Water (*Quercus nigra*)	Louisiana.	10.8	.64	44	9,200	16,000	2,060	22.6	44	3,930	7,200	1,320	2,010	940	1,450	1,220
White (*Quercus alba*)	Arkansas, Louisiana, Indiana.	11.5	.69	48	8,300	15,200	1,780	14.8	38	4,350	7,610	1,340	2,090	800	1,540	1,370
Willow (*Quercus phellos*)	Louisiana.	9.8	.72	49	10,700	16,400	2,040	16.0	44	4,910	8,230	1,640	1,800	1,430	1,530	1,620
Yellow (*Quercus velutina*)	Arkansas, Wisconsin.	11.6	.61	42	8,000	14,100	1,650	13.7	41	4,780	6,660	1,160	1,970	820	1,400	1,210
Persimmon (*Diospyros virginiana*)	Missouri.	5.5	.81	53	15,400	23,700	2,460	16.9	35	9,210	14,050	3,910	2,670	1,520	3,730	3,180
Poplar, yellow (*Liriodendron tulipifera*)	Tennessee.	6.1	.41	27	8,400	11,800	1,610	7.5	22	4,470	7,480	740	1,170	570	590	450
Sassafras (*Sassafras sassafras*)	Tennessee.	6.8	.46	31	7,700	10,600	1,220	9.5	31	3,740	6,060	1,470	1,380	620	670	690
Sycamore (*Platanus occidentalis*)	Indiana, Tennessee.	9.2	.50	34	7,600	11,300	1,510	9.2	28	4,260	6,280	1,010	1,460	750	970	810
Walnut, black (*Juglans nigra*)	Kentucky.	4.8	.57	37	14,500	17,900	1,820	9.2	33	7,880	10,660	1,960	1,480	780	1,110	1,080
Willow, black (*Salix nigra*)	Wisconsin, Missouri.	6.4	.38	26	5,600	7,600	830	6.8	16	2,880	5,030	710	1,340	470	680	500
Conifers																
Cedar, incense (*Libocedrus decurrens*)	California, Oregon.	5.1	.36	24	7,400	9,400	1,300	4.9	17	6,400	7,200	840	900	270	1,040	520
Port Orford (*Chamæcyparis lawsoniana*)	Oregon.	9.0	.45	31	8,900	14,500	2,040	....	39	7,700	7,750	1,020	1,500	630	950	700
Western red (*Thuja plicata*)	Washington, Montana.	7.4	.34	22	6,100	8,800	1,250	6.4	16	5,390	6,320	700	920	180	750	380
White (*Thuja occidentalis*)	Wisconsin.	11.2	.31	22	5,100	6,700	810	4.7	12	2,840	4,140	390	900	240	470	340
Cypress, bald (*Taxodium distichum*)	Louisiana, Missouri.	9.0	.44	30	8,700	11,300	1,540	7.3	26	5,970	7,690	910	1,080	280	800	550
Douglas fir (*Pseudotsuga taxifolia*)	Montana, Wyoming.	9.4	.44	30	6,900	10,300	1,460	6.5	28	5,320	7,090	950	1,080	320	750	660
Douglas fir (*Pseudotsuga taxifolia*)	Washington, Oregon.	6.2	.51	34	10,600	14,000	2,210	8.4	33	9,260	10,680	1,220	1,270	330	920	810
Fir, amabalis (*Abies amabilis*)	Washington.	9.3	.39	27	7,000	10,600	1,600	10.3	24	5,070	6,540	580	1,180	290	720	470
Balsam (*Abies balsamea*)	Wisconsin.	4.8	.38	25	7,300	9,900	1,440	5.4	23	.....	6,640	530	790	180	740	500
Grand (*Abies grandis*)	Montana, Oregon.	6.8	.41	27	7,100	11,000	1,790	8.3	32	5,970	7,060	850	1,000	190	820	560
Noble (*Abies nobilis*)	Oregon.	8.4	.39	26	7,700	12,000	1,750	9.4	27	6,140	7,240	850	1,090	130	860	470
White (*Abies concolor*)	California	9.6	.38	26	7,000	9,800	1,490	5.5	14	4,180	6,150	720	1,060	260	780	460
Hemlock (eastern) (*Tsuga canadensis*)	Tennessee, Wisconsin.	8.6	.42	28	7,200	9,700	1,300	5.8	24	5,240	7,060	1,060	1,160	190	860	490
(Western) (*Tsuga heterophylla*)	Washington.	5.4	.42	28	8,000	10,800	1,520	6.1	26	7,780	7,910	830	1,170	170	1,020	620
Larch, western (*Larix occidentalis*)	Montana, Washington	8.3	.54	36	10,100	13,500	1,830	8.2	34	8,420	9,640	1,280	1,530	340	1,380	870
Pine, jack (*Pinus divaricata*)	Wisconsin.	6.1	.44	29	6,500	9,700	1,400	5.1	37	.....	7,770	1,150	1,330	440	870	740
Loblolly (*Pinus tæda*)	Florida.	6.5	.57	38	11,700	15,600	2,130	9.0	26	7,980	11,300	1,600	1,720	370	1,030	840

TABLE XI.—RESULTS OF TESTS ON SMALL CLEAR AIR-DRY PIECES OF WOOD[a]—*Continued*

Common and botanical name	Locality where grown	Moisture content (per cent)	Specific gravity, oven dry, based on volume when air dry	Weight per cubic foot (air dry) (pounds)	Static bending				Impact bending, height of drop causing complete failure, 50-pound hammer (inches)	Compression parallel to grain		Compression perpendicular to grain—fiber stress at elastic limit (pounds per square inch)	Shearing strength parallel to grain (pounds per square inch)	Tension perpendicular to grain (pounds per square inch)	Hardness, load required to imbed a 0.444-inch ball to one-half its diameter	
					Fiber stress at elastic limit (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)	Work in bending to maximum load (inch-pounds per cubic inch)		Fiber stress at elastic limit (pounds per square inch)	Maximum crushing strength (pounds per square inch)				End (pounds)	Side (pounds)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Pine,																
Lodgepole (*Pinus contorta*)..	Colorado, Montana, Wyoming.	7.1	0.43	28	9,000	11,500	1,460	7.6	20	6,270	7,300	1,120	980	380	640	500
Longleaf (*Pinus palustris*).	Florida, Louisiana, Mississippi.	9.2	.66	42	11,800	16,700	2,200	11.3	32	9,250	10,880	1,670	1,640	420	1,140	1,020
Norway (*Pinus resinoso*)....	Wisconsin.	12.5	.48	34	9,200	12,300	1,790	9.9	25	5,660	7,080	830	1,260	470	700	600
Shortleaf (*Pinus echinata*)..	Arkansas, Louisiana.	11.0	.54	38	9,200	13,900	1,970	10.1	36	7,080	8,660	1,310	1,390	410	940	880
Slash (*Pinus caribaca*)....	Florida.	8.8	.66	45	12,400	18,300	2,220	13.1	42	9,160	11,890	1,620	1,920	650	1,200	1,160
Sugar (*Pinus lambertiana*)..	California.	11.4	.37	26	6,400	8,600	1,210	5.0	17	4,740	5,190	640	1,080	350	650	460
Western white (*Pinus monticola*).....	Montana.	7.9	.43	29	7,900	11,500	1,690	10.0	29	5,810	7,840	810	590	.....	470	420
Western yellow (*Pinus ponderosa*).....	Colorado, Montana, Arizona, Washington, California.	10.8	.41	28	6,900	9,800	1,340	6.4	16	4,490	5,990	760	1,160	410	570	460
White (*Pinus strobus*).....	Wisconsin.	9.9	.39	27	7,000	9,600	1,420	6.4	18	5,070	6,360	760	1,070	340	610	470
Spruce, Engelmann (*Picea engelmanni*).....	Colorado.	14.8	.32	24	4,500	6,800	1,030	5.4	15	2,980	3,810	520	910	.....	390	290
Red (*Picea rubens*).....	New Hampshire, Tennessee.	10.8	.41	28	7,400	10,800	1,550	8.7	28	5,470	6,380	620	1,160	380	670	510

Spruce, Sitka (*Picea sitchensis*)	Washington.	8.9	.38	26	7,200	11,200	1,610	10.4	25	.....	5,770	1,010	1,210	...	780	330
White (*Picea canadensis*)...	New Hampshire, Wisconsin.	9.6	.40	28	5,900	9,200	1,390	8.2	20	4,620	6,020	590	970	350	760	560
Tamarack (*Larix laricina*)....	Wisconsin.	11.0	.53	37	8,400	12,000	1,680	7.1	23	5,150	7,590	1,080	1,370	410	720	640
Yew, western (*Taxus brevifolia*.....	Washington.....	9.2	.63	43	10,100	16,800	1,460	18.4	30	4,720	9,220	2,680	2,480	410	2,330	1,800

[a] From NEWLIN, J. A. and WILSON, T. R. C., "Mechanical Properties of Woods Grown in the United States." United States Department of Agriculture *Bull.* **556.**

This table is to be considered supplementary to Table X because it is based on a smaller number of tests. It should be noted that the moisture content is not uniform, and in comparing one species with another allowance must be made for differences in moisture content. A table for adjusting values to different moisture contents around 12 per cent is given in Chap. V, Art. **54.** In Table X the moisture content is above the fiber-saturation point and what variations occur do not influence the strength.

The values in this table are averages of a limited number of tests. Considerable variation from these values may occur on account of variations in the density of the wood of any one species. Defects are not considered in this table.

XIV for the maximum crushing strength parallel to the grain of structural timbers.

When wood fails in compression along the grain, the failure often is indicated by a buckling or wrinkling of the fibers, forming a slight ridge or offset which frequently extends at more or less of an angle across the grain on the tangential face, but at right angles to the grain on the radial face. The buckling of the fibers is known as a "compression failure." In green wood the fibers usually bend over in a gradual curve, while in dry wood they buckle more abruptly. In very dry wood the fibers often

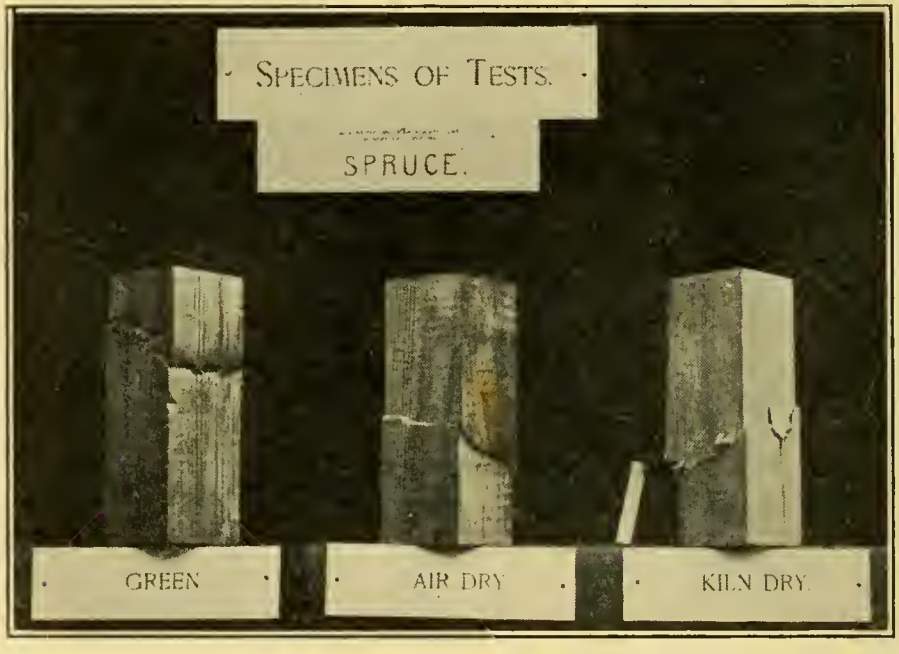


FIG. 39.—Manner of failure in compression tests of spruce of different moisture conditions. (*From Forest Service Bull.* 70.)

separate or split apart before any decided buckling takes place. The failure does not occur suddenly, except in very dry pieces, but rather gradually, allowing the wood to suffer considerable shortening before it will show any decrease in strength. Figure 39 illustrates the manner in which green and dry spruce fail in end compression.

If a column of uniform cross-section is more than ten or twelve times longer than its least transverse dimension, bending may take place before the maximum crushing strength is reached. If the column bends, compression occurs chiefly on the concave side which reduces the load that can be sustained as compared with uniform compression in short pieces. To reduce the bend-

ing and at the same time keep the weight or amount of material used at a minimum, long columns usually are spindle shaped or are reinforced at the middle.

In compression perpendicular to the grain no definite maximum load is reached beyond which there is an abrupt decrease in strength but more and more fibers become flattened as the load is increased. The strength values usually are expressed in pounds per square inch, or other unit stress, beyond which the fibers become flattened to such an extent that they will not resume their original shape when the load is relieved, or, what is the same thing, the unit stress beyond which the rate of compression increases more rapidly than the rate at which the load increases. This point is known as the *elastic limit*. Tables X and XI give the fiber stress at the elastic limit in compression perpendicular to the grain for green and air-dry material. Strength in compression across the grain is important in determining the size of bearings and of tenons and mortises.

35. Tensile Strength.—The tensile strength of a material is indicated by its resistance to forces which tend to pull it apart. Wood shows its greatest strength in tension along the grain. In fact, it is so strong that it is exceedingly difficult to pull wood apart lengthwise, since bolts or other fastenings usually will shear out at the ends before the stick fails in tension. Because it is necessary to make the end fastenings very massive, wood is rarely used where high tensile stresses are developed, steel rods, cables, or chains being used instead. For this reason tension tests along the grain usually are omitted from timber tests. Table XII gives the results of a small number of tests on the tensile strength of unseasoned wood along the grain. Examples of wood under tension are the reach of a wagon, pump rods, pitmans, and collar beams in buildings.

The tensile strength of wood has an important bearing on the strength of beams because the lower part of a loaded beam is under severe tension while the upper part is under compression. Failure in beams usually occurs first by compression or buckling in the upper part, and then as the load increases, the beam snaps across the bottom. In very dry pieces the compression often is not apparent.

The ratio of the strength in compression along the grain to the strength in tension along the grain has an important relation to the toughness of wood and its suitability for permanent bending.

TABLE XII.—STRENGTH OF VARIOUS WOODS IN TENSION PARALLEL TO GRAIN

(From tests of small clear specimens of green timber)

Species	Number tests averaged	Number trees represented	Moisture content per cent	Specific gravity	Tension parallel to grain (pounds per square inch)	Probable variation of individual from average (pounds per square inch)
Mahogany, African	20	5	49.7	.457[b]	15,110	2,075
Central American	27	7	50.1	.492[b]	16,400	2,400
Maple, sugar	6	4	47.1	.550	14,900	.....
Oak, Northern white[a]	50	18	49.9	.645[b]	14,012	2,900
Cedar, Port Orford	59	9	35.0	.399	11,730	1,210
Douglas fir (1)	63	10	24.1	.530[b]	16,200	1,735
Douglas fir (2)	48	10	23.0	.477[b]	13,300	2,050
Fir, white	10	10	50.0	.369	7,972	1,400
Hemlock, western	7	2	39 to 98	.390	7,716	1,570
Pine, Norway	4	2	31.0	.401	9,760	.....
White	42	9	41 to 86	.351	9,580	1,405
Redwood	13	5	40 to 155	.400	9,600	1,170

(1) Specimens from the 8 feet immediately above stump.
(2) Specimens from the fifth 8 feet above stump and higher.
(1) and (2) from same trees.
[a] Not identified as to species.
[b] Specific gravity based on oven-dry weight and volume. Other specific gravities based on oven-dry weight and volume as tested.

A piece in which the tensile strength is several times that of the compressive strength can be bent a great deal before it breaks, because of the buckling of the fibers which takes place on the compression side before failure occurs on the tension side. On the other hand, if the tensile strength is not much greater than the compressive strength, the stick will snap across on the tension side with comparatively little bending. In such a case the fracture usually occurs more or less abruptly across the grain, giving the wood the characteristic appearance of what is commonly known as *brash*.

Moisture and heat decrease the strength in compression more than the strength in tension, and, hence, a steamed or boiled piece of wood can be bent more before it breaks on the convex side than can a cold dry piece.

Wood is comparatively weak in tension across the grain, the same quality of wood usually showing only one-tenth to one-thirtieth as much tensile strength transversely as longitudinally. Knots and cross grain are highly weakening when in the lower part of a

beam, since the tension acts more or less across the grain wherever the grain does not run parallel to the axis of the beam.

In most woods there is little difference in the tensile strength radially and tangentially. Some woods when seasoned show a considerably higher tensile strength when the surface of failure

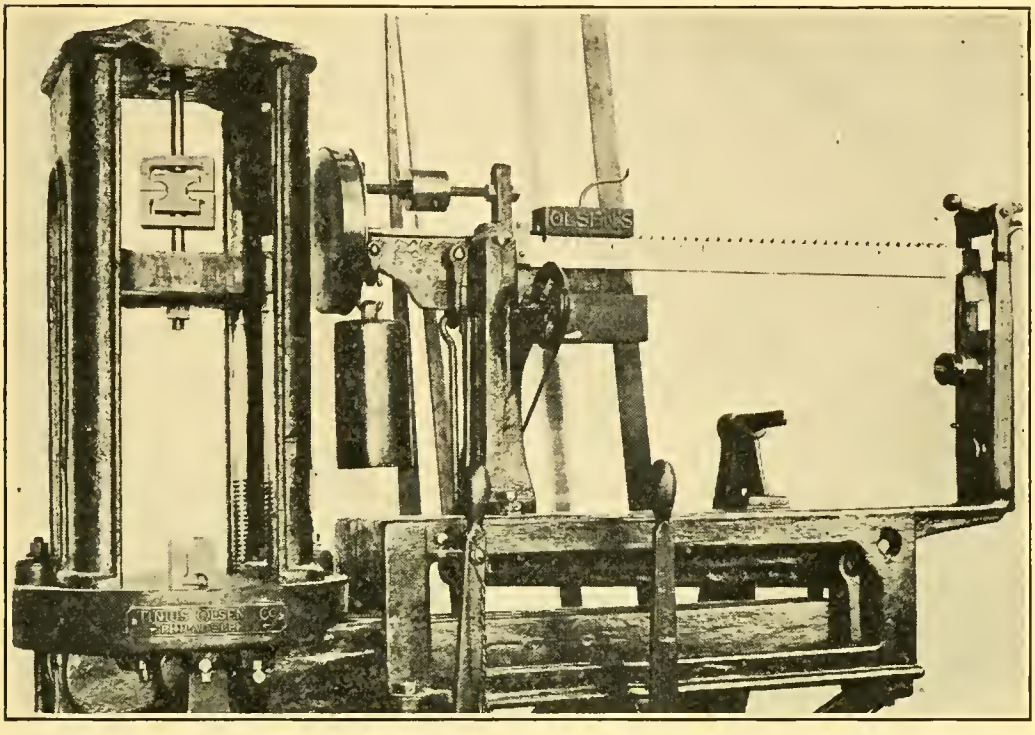


FIG. 40.—Wood specimen in machine for test in tension at right angles to the grain. (*Courtesy, Forest Products Laboratory.*)

is at right angles to the rays, that is, in the direction of the annual rings than when it is parallel to the rays. Tables X and XI show the average of the radial and tangential tensile strengths for various native woods, green and air dry. The strength is determined by measuring the force required to pull a block of wood

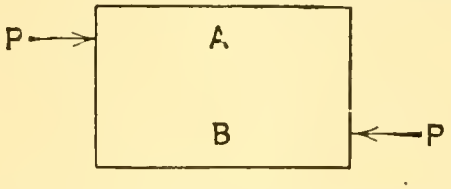


FIG. 41.—Forces P and P' tending to produce shear between A and B.

apart as illustrated in Fig. 40. This force in pounds divided by the area in inches of the surface of failure gives the strength in pounds per square inch.

36. Shearing Strength.—Shearing strength is the resistance a material offers to forces which tend to slide one portion of

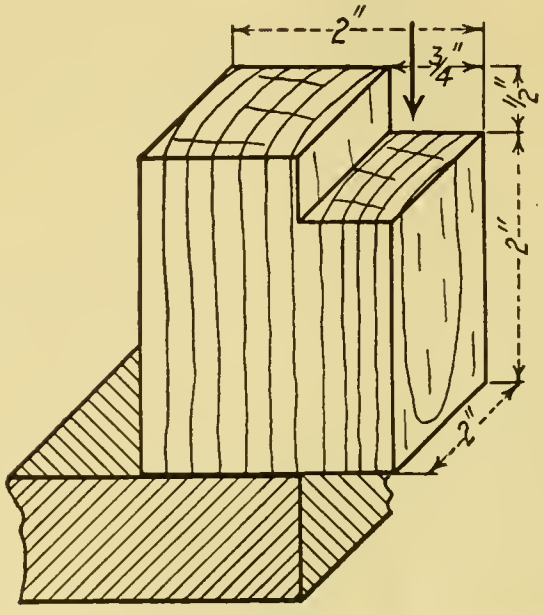


FIG. 42.—Wood specimen for shear test along the grain.

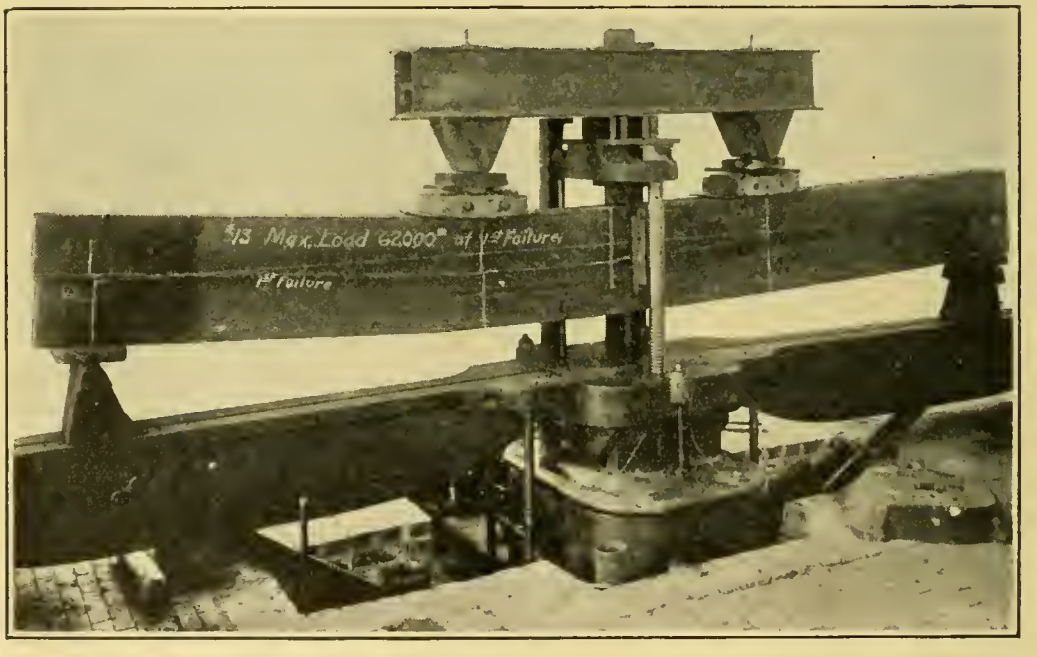


FIG. 43.—Large beam in testing machine. First failure was in horizontal shear. (*Courtesy, U. S. Forest Service.*)

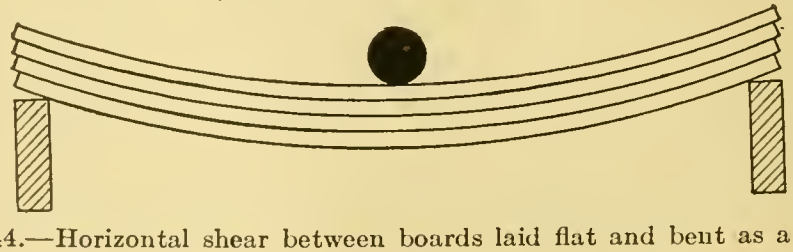


FIG. 44.—Horizontal shear between boards laid flat and bent as a beam.

the material over the remaining portion. Figure 41 illustrates two forces, P and P', which tend to slide the portion A to the right and the portion B to the left.[1] The force required to shear wood across the grain is much greater than that required to shear the same area along the grain. Failure seldom occurs by pure transverse shear, and, therefore, strength tests usually do not include this property.

The shearing strength with the grain is determined by the force required to shear off a projecting lip from a block of wood as shown in Fig. 42. This force in pounds divided by the cross-sectional area of the sheared surface in inches gives the shearing strength in pounds per square inch. The shearing strength along the grain of green and air-dry wood is given in Tables X and XI. Whether the plane of shear is tangential or radial to the annual rings generally makes little difference as far as the strength of green or well-seasoned wood is concerned, although seasoning checks, because they occur mostly along the rays, weaken wood in longitudinal shear when the surface of failure is radial. An example of direct shear along the grain is found when tennons or bolts pull out at the ends of wooden members.

[1] This action is similar to that which takes place in cutting with ordinary shears.

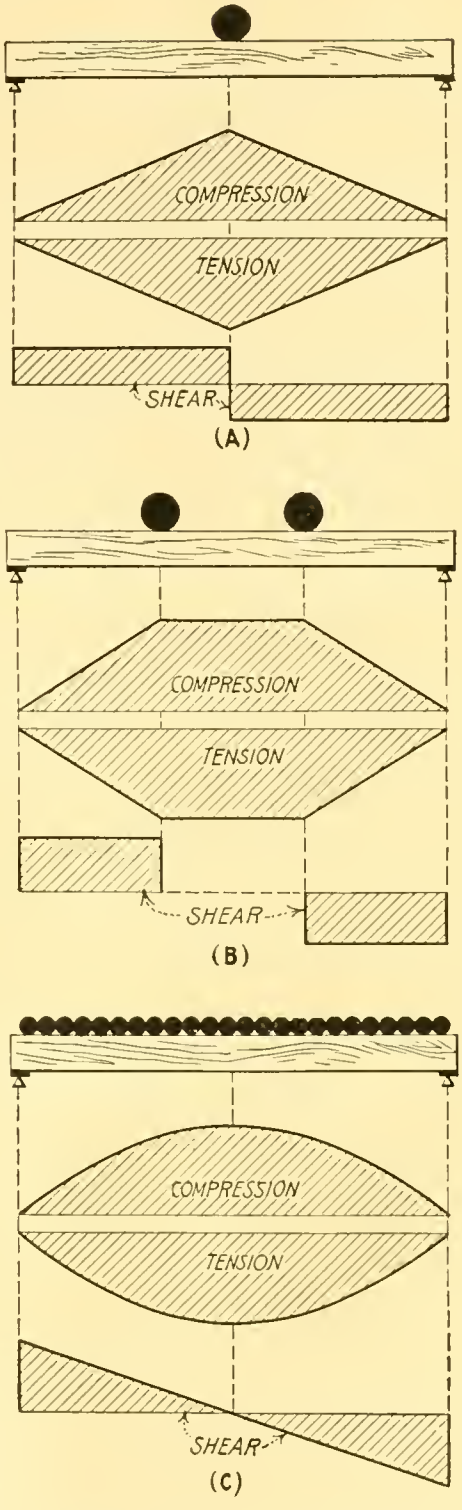


FIG. 45.—Diagrams showing variation in compression and tension stresses in extreme upper and lower fibers respectively, and in shear along the neutral plane from end to end of a timber under center loading in A, third-point loading in B, and uniform loading in C, as calculated from formulas ordinarily used.

Shear failure also often occurs along the middle of overloaded beams as shown in Fig. 43. This is commonly known as horizontal shear. It usually happens in timbers which are badly checked or affected with shake, although it may occur in beams without defects under certain loading conditions.

Horizontal shear is due to the compression and tension stresses set up in a beam under load. These stresses are not uniform and in the same direction throughout the beam, and, hence, there is a tendency toward movement or sliding of the parts over each other.

That horizontal shearing stresses are present in a beam can be seen by placing several boards on top of each other on two supports near the ends and then placing a weight on them at the middle. As the boards bend they slide over each other so that the ends of each one project beyond those of the one below it, as illustrated in Fig. 44.

Figure 45 shows how the shearing stresses vary from end to end in a simple beam under various forms of loading, and Fig. 46 shows how they vary from the upper to the lower surfaces of a beam.

The tendency to shear is greatest at the neutral plane, but failure by shear may also take place considerably above or below the neutral plane if these portions are weakened by shakes or checks. A beam sheared horizontally is no stronger than the combined strength of the separated parts, which is only about half as much as the strength of an otherwise similar timber which resists shear successfully. This is true because the load a beam will carry varies as the square of the height (page 101), and the whole beam will carry four times as great a load as the upper or lower half taken by itself, and twice as much as the combined upper and lower halves when separated. (It is assumed in this case that the shear takes place in the middle of the beam which is not always the case and that there is no friction between the parts.) A continuous load which causes horizontal shear is also enough to break the timber transversely after shear has taken place, unless the resistance to shear has been greatly reduced by checks or shakes, or the timber is very short for its height. Beams which are comparatively short are more likely to fail in horizontal shear than comparatively long ones because they are often subjected to loads which develop the maximum shearing stress.

37. Cross-breaking Strength, or Strength as a Beam.—If a wooden beam is supported at both ends and a gradually increasing load is placed on it between the supports it will bend more and more as the load increases until it finally breaks. The bending of the beam causes the fibers in the upper part to be in compression and in the lower part to be in tension as already explained in Art. **35**. The compression and tension stresses are greatest in the extreme top and bottom fibers respectively and gradually become less toward the neutral plane[1] where these stresses are entirely absent, Fig. 46. Therefore, the strength of a beam depends principally on the maximum strength of the fibers in the extreme upper and lower portions. If these

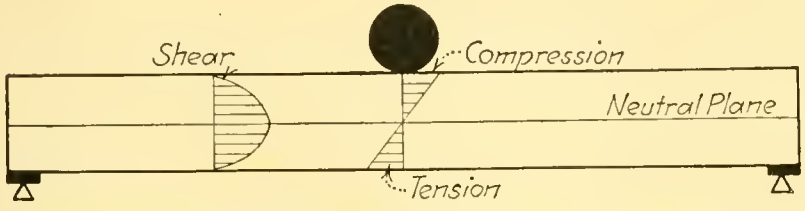


FIG. 46.—Diagram showing variation in compression, tension, and shearing stresses from top to bottom of a beam under load.

fibers are easily compressed or torn apart, the beam is comparatively weak; on the other hand, if the extreme fibers will endure great stresses before they give way, the beam is comparatively strong.[2]

The strength of wood as a beam is expressed in terms of the stress in the extreme fiber when under breaking load. This is known as the *modulus of rupture*. It is a computed stress and not the actual stress in the fibers. It is, however, a universally accepted term, and values for the modulus of rupture are quite comparable for various species and sizes of timbers. It is commonly expressed in pounds per square inch of cross-section.

[1] Since wood is weaker in compression than in tension the fibers on the compression side of a beam usually fail first which causes the neutral plane to shift from the middle toward the tension side.

[2] Since the material furthest from the neutral axis is most effective in resisting bending stresses it is a common practice to build steel beams so as to resemble the letter I in cross-section. Wooden beams which must be as light as possible for their strength, as airplane wing beams, are given a similar shape by routing out the sides.

In a rectangular beam the modulus of rupture is entirely independent of the size of the beam but varies with the kind and quality of the wood. The load required to produce the maximum stress in the extreme fibers, however, varies with the dimensions of the beam. The maximum load that a beam of any given kind of material will support varies inversely as the length, directly as the width, and directly as the square of the height of the beam. For example, if a stick of green tamarack 2 by 2 inches and 4 feet long supported at both ends will carry a maximum load of 800 pounds at the middle, the same quality of timber 8 feet long, other dimensions remaining the same, will support only half as much, or 400 pounds (4 : 8 :: 400 : 800). If the 4-foot stick were 4 inches wide and 2 inches high, it would support twice as much, or 1,600 pounds (2 : 4 :: 800 : 1,600). If the stick were 4 inches high and 2 inches wide, it would carry four times as much as the 2 by 2, namely, 3,200 pounds ($2^2 : 4^2 :: 800 : 3{,}200$).

The relations existing between the dimensions of a rectangular beam, the maximum load it will carry at the center, and the modulus of rupture are expressed in the following formulas: $\frac{P \times l}{b \times h^2} \times \frac{3}{2} = R$, in which P represents the breaking load, l the length of span, b the breadth or width, h the height or depth of the stick, and R the modulus of rupture.[1]

This can be made clear by substituting the values given above for the green tamarack. Thus, in the first case, having a stick 4 feet long, 2 inches wide, and 2 inches high:

$\frac{48 \times 800}{2 \times 2^2} \times \frac{3}{2} = 7{,}200$ pounds per square inch = modulus of rupture.

In the second case, having a similar stick but 8 feet long:

$\frac{96 \times 400}{2 \times 2^2} \times \frac{3}{2} = 7{,}200$ pounds per square inch = modulus of rupture.

[1] If a beam is uniformly loaded from end to end, it will sustain twice as much weight as at center loading, and the formula becomes $\frac{P \times l}{b \times h^2} \times \frac{3}{4} = R$. If the load is applied at third points, that is, half of the load at each of the two points one-third of the length of the beam from the ends, the formula becomes $\frac{P \times l}{b \times h^2} = R$. In large beams the weight of the timbers should be taken into consideration, making the formula for third-point loading $\frac{l(P \times 0.75W)}{b \times h^2} = R$, where W equals the weight of the beam.

In the third case, having a stick similar to the first but 4 inches wide:

$$\frac{48 \times 1{,}600}{4 \times 2^2} \times \frac{3}{2} = 7{,}200 \text{ pounds per square inch} =$$

modulus of rupture.

In the fourth case, having a stick similar to the first but 4 inches high:

$$\frac{48 \times 3{,}200}{2 \times 4^2} \times \frac{3}{2} = 7{,}200 \text{ pounds per square inch} =$$

modulus of rupture.

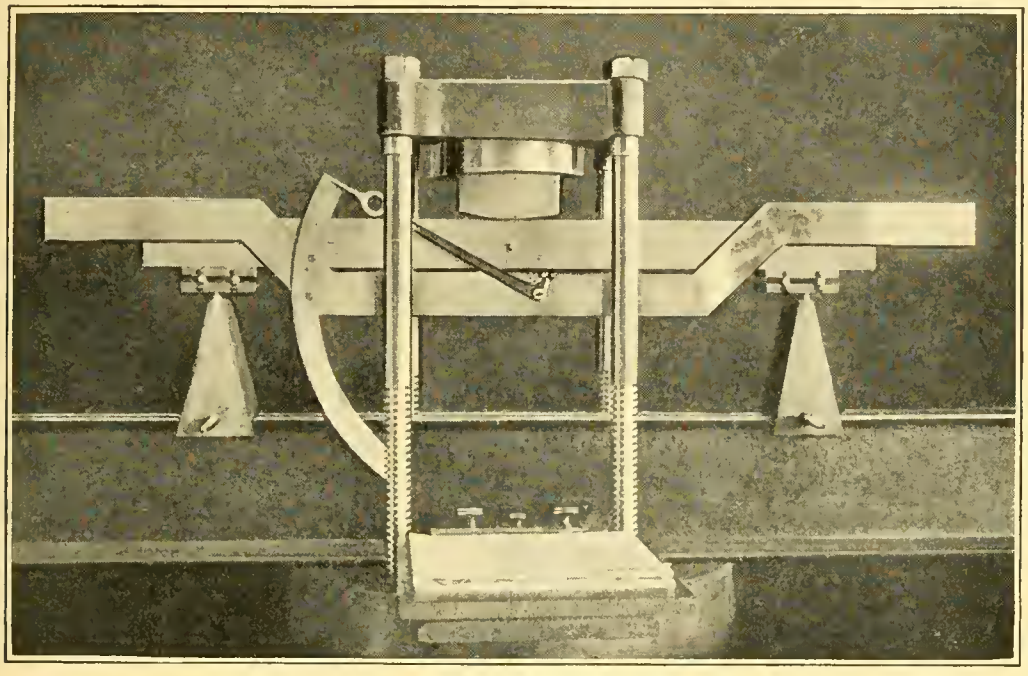


FIG. 47.—Small beam, 2 by 2 inches, in testing machine ready for bending test. Note deflectometer for measuring deflection. (*Courtesy, U. S. Forest Service.*)

For green spruce the modulus of rupture would be less and for green hickory more. (See Tables X and XI for the average moduli of rupture of small clear pieces of important American woods.) Large timbers have a lower modulus of rupture than small clear pieces cut from them because they contain more or less defects even when carefully selected so as to eliminate defects as far as possible. Table XIV shows the modulus of rupture of large timbers and small clear pieces cut from them and the ratio between the two. Figures 43 and 47 show methods of testing large and small beams respectively.

If the modulus of rupture of a given species is known, the maximum load that a certain sized timber of that species and of

average quality may be expected to carry can be computed by means of the above formulas. Thus, to determine the load an unseasoned 6 by 8-inch Norway pine beam 12 feet long will support at the middle, we find from Table XIV that the modulus of rupture of green Norway pine of structural size is 3,864 pounds per square inch. Substituting known values in the formula:

$$\frac{3 \times P \times 144}{2 \times 6 \times 8^2} = 3{,}864$$

$$3 \times P \times 144 = 3{,}864 \times 2 \times 6 \times 8^2$$

$$P = \frac{3{,}864 \times 2 \times 6 \times 8^2}{3 \times 144}$$

$$P = 6{,}869\ \tfrac{1}{3} \text{ pounds}$$

Conversely, if the weight that a beam must bear is known the necessary size may be computed. In practice only one-third to one-fourth of the values for green structural timbers, or one-fifth of the values for small clear green pieces, or one-sixth to one-tenth of the values for small clear dry pieces is used in calculating the size of timbers required. This is done in order to make allowance for variability and imperfections in the timber, accidental excess loads, and as explained in Art. **38,** to place the stress in beams well within the elastic limit. These reduced values are known as *safe working stresses* (Art. **43** and Table XV), and their relation to the maximum strength is known as the *factor of safety.*[1] Thus a factor of 5, 6, 10, or some other figure may be used, depending upon the character of the structure and the table on which the computation is based.

Because the cross-breaking strength of timbers under slowly applied loads increases much more with an increase in height than with an increase in width, beams are nearly always made deeper than wide. However, if the height is more than four times the width, timbers have a tendency to twist when loaded, thereby weakening the structure. For this reason joists are usually cross-bridged if 8 or more inches high and if the span is 10 or more feet.

38. Stiffness.—The stiffness of a beam is a measure of its ability to resist deformation under bending stresses.[2] It is a

[1] This is not a true factor of safety, as is explained in Art. **43.**

[2] *Flexibility* is often considered to be the opposite of stiffness, but it involves the capacity to bend a great deal without breaking rather than bending easily. This property is important in the manufacture of bent woodwork.

property entirely independent of the cross-breaking strength, although woods which rank high in stiffness also rank high in breaking strength as a beam. In many structures the stiffness of the members is so essential that it is necessary to use a greater number or larger sizes of beams and joists than are required to carry the anticipated load safely. If floor beams, for example, are

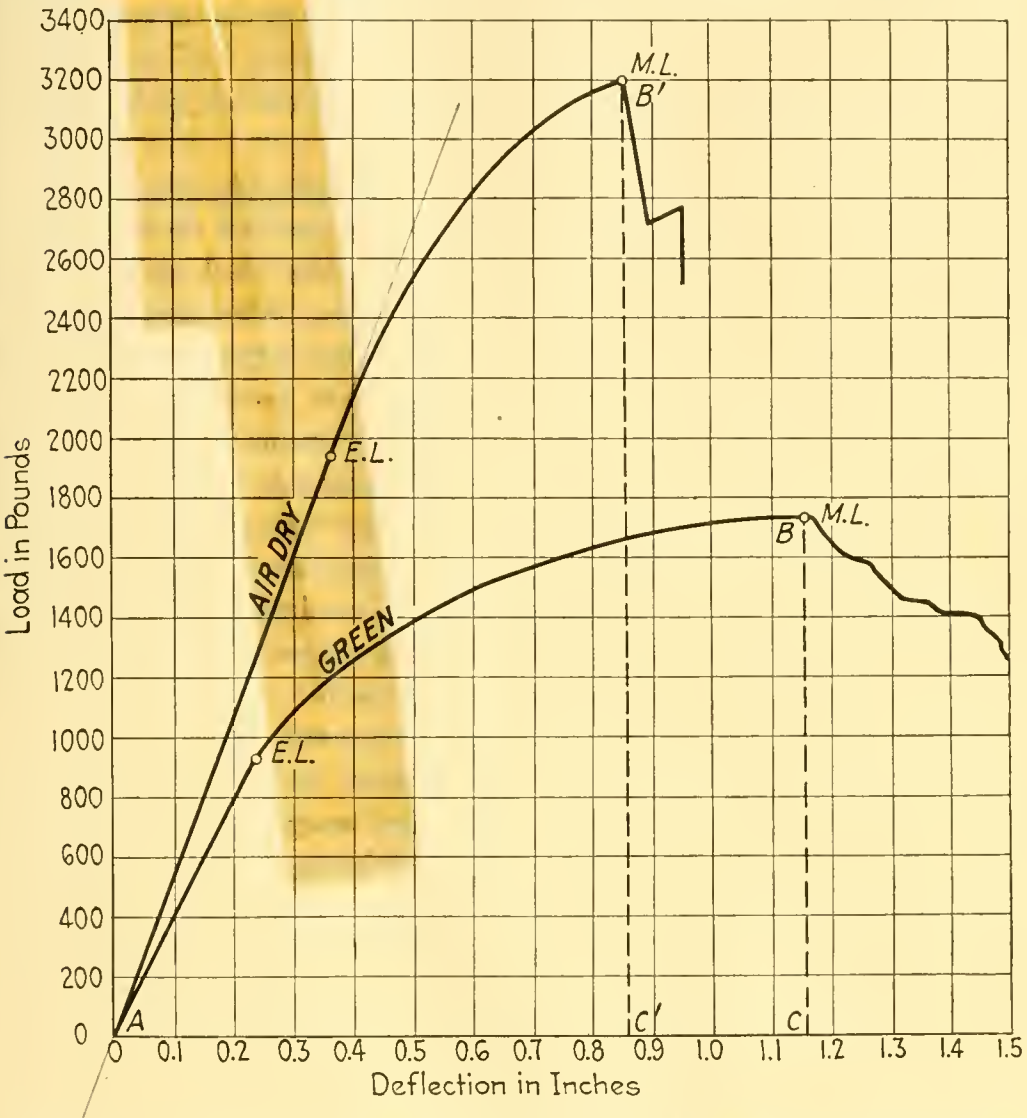


FIG. 48.—Average load-deflection curves for center loading in static bending tests on clear green and air-dry white ash specimens 2 by 2 inches with 28 inches between supports. *E.L.*, elastic limit; *M.L.*, maximum load. The areas *ABC* and *AB'C'* represent the work to maximum load for green and air-dry material respectively. Constructed up to the maximum load from values for forest grown white ash as given in Tables X and XI.

not stiff enough the floor will jar as one walks over it, and it may sag under its load causing it to become concave and the plaster on the walls to crack and crumble.

The deflection of a beam is directly proportional to the load up to a certain limit. For example, if a load of 5 pounds applied

to the middle of a 2 by 2 inch seasoned elm stick 10 feet long and supported at both ends bends the stick $\frac{1}{10}$ inch at the middle, a load of 10 pounds will bend it $\frac{2}{10}$ inch, and a load of 20 pounds will bend it $\frac{4}{10}$ inch. Beyond a certain limit, however, the bending will increase faster than the load, and ultimately as more load is added the stick will break. The point at which the deflection increases faster than the load is the elastic limit (Fig. 48). A stick bent beyond the elastic limit will not regain its original shape when the load is removed; that is, it is permanently deformed.

The stiffness of beams and columns is expressed by the *modulus of elasticity*. The numerical value of the modulus of elasticity, when expressed in pounds and inches, is the load required to stretch a piece of a material 1 inch square in cross-section to double its length, provided it is not stressed beyond the elastic limit. Wood and most other materials, of course, cannot be stretched to that extent, so this applies only theoretically. Within the elastic limit the stiffness is proportional to the modulus of elasticity; that is, a wood with a modulus twice that of another is twice as stiff and will bend half as much under the same load. See Tables X and XI for the average moduli of elasticity of the more important native woods. In general, conifers rank higher in stiffness than hardwoods of the same weight, and wood which has been dried is stiffer than when green.

The mathematical relations which exist between the dimensions and the deflection of a rectangular beam may be summed up as follows: the deflection varies directly (or the stiffness inversely) as the cube of the length, inversely (or the stiffness directly) as the width, and inversely (or the stiffness directly) as the cube of the height. For example, if the above-mentioned elm stick were twice as long it would bend eight times as much, or $\frac{8}{10}$ inch, under the same load, provided, of course, that the deflection were still within the elastic limit ($10^3:20^3::\frac{1}{10}:\frac{8}{10}$). If the width were doubled, the deflection would be one-half as much, or $\frac{1}{20}$ inch ($2:4::\frac{1}{20}:\frac{1}{10}$). If the height of the stick were doubled, the deflection would be one-eighth as much, or $\frac{1}{80}$ inch ($2^3:4^3::\frac{1}{80}:\frac{1}{10}$).

The relations of the dimensions of a rectangular beam loaded at the center, of the load, of the deflection, and of the modulus of elasticity to each other are shown in the formula

$$\frac{P' \times l^3}{b \times h^3 \times D} \times \frac{1}{4} = E, \text{ or } \frac{P' \times l^3}{b \times h^3 \times E} \times \frac{1}{4} = D$$

in which P' is any load within the elastic limit, D the deflection under that load, l the length between supports, b the breadth or width, h the height, and E the modulus of elasticity. The stiffness of columns loaded on end is proportional to the stiffness of beams, but the actual deflection is computed by a different formula for which books on mechanics may be consulted.

The modulus of elasticity of wood is determined by observing the load and corresponding deflection within the elastic limit in bending a piece in a testing machine and substituting these values and the dimensions of the stick in the above formula.

By ascertaining the modulus of elasticity of a given kind of wood from tables, and knowing the dimensions of the timber used, the deflections can be calculated for a given load. Similarly, the load which will produce a certain deflection can also be calculated, provided in each case that the load is within the elastic limit and that the wood is of average quality and does not contain influencing defects.

Because the stiffness increases as the cube of the depth and only directly as the width, it is all the more desirable to have joists, rafters, and beams deep rather than broad.

39. Toughness, or Shock-resisting Ability.—The term "toughness" as used here means the capacity of wood to absorb energy, or resist shocks. In order to rank high in this respect the wood must be strong in cross-breaking and at the same time it must bend considerably before it breaks. That is, it must be able to absorb a comparatively large amount of work. This is the sense in which "toughness" commonly is used in connection with handles, oars, singletrees, spokes, or other articles subjected to shocks or stresses of very short duration.[1] It may include slight permanent or semi-permanent deformation and some injury to the wood fibers.

Toughness is determined from static and impact bending tests. In static bending tests it is determined from the amount of work required to bring the head of the machine down to the

[1] "Toughness" as used with respect to wood also has several other meanings. A piece of wood is said to be tough if it can be bent or twisted a great deal without breaking irrespective of the force required. In this sense willow reeds would rank among the toughest of woods, and green wood would be much tougher than dry wood. When used with this meaning, toughness is made synonymous with flexibility. Wood is also said to be tough if it hangs together tenaciously after failure has started, and if it is difficult to split.

TABLE XIII.—MECHANICAL PROPERTIES OF VARIOUS MATERIALS OTHER THAN WOOD[a]

Material	Strength in compression (pounds per square inch)	Strength in tension (pounds per square inch)	Modulus of rupture (pounds per square inch)	Modulus of elasticity (1,000 pounds per square inch)
Cast iron, gray	90,000 to 108,000	15,000 to 18,000	30,000 to 36,000	12,000 to 14,000
Wrought iron	28,000 to 34,000	42,000 to 52,000	42,000 to 52,000	26,000 to 29,000
Medium steel	37,000 to 44,000	60,000 to 70,000	37,000 to 44,000	30,000
Tempered spring steel		130,000 to 200,000		30,000
Granite	19,400		1,850	7,300
Limestone	9,500		1,400	8,460
Sandstone	9,300		1,400	3,000
Common brick	4,000			2,000
Brick masonry:				
In lime mortar	0.14 × compressive strength of brick used.			
In cement mortar	0.23 × compressive strength of brick used.			
Concrete:				
Gravel aggregate:				
1 : 1 : 2[b]	3,000			
1 : 3 : 6	1,400			
Cinder aggregate:				
1 : 1 : 2	800			
1 : 3 : 6	400			

[a] From MARKS, L. S., "Mechanical Engineers' Handbook." McGraw-Hill Book Company, New York.

[b] One part cement, one part sand, two parts gravel.

greatest load the stick will carry. This is known as the *work to maximum load.* Since work is the product of the force times the distance through which it acts, the values are determined by the areas in load-deflection diagrams as are indicated by ABC and $AB'C'$ in Fig. 48. If the deflection were proportional to the load up to the breaking point, this would be equal to one-half the deflection times the maximum load.

A piece of oak and a piece of yellow pine may have the same strength as a beam, but oak usually bends more than pine before it breaks; that is, more work must be performed in breaking it, and for this reason it is said to be tougher than pine. On the other hand, a piece of white elm and a piece of rock elm may bend to the same extent before they break, but the rock elm is considered tougher because it takes more of a load to break it. The conifers as a class will not bend so far as the hardwoods before failure occurs (although weight for weight, they will endure

TABLE XIV.—AVERAGE STRENGTH VALUES, GREEN STRUCTURAL TIMBERS WITH ORDINARY DEFECTS AND SMALL SPECIMENS OF GREEN MATERIAL WITHOUT DEFECTS[a]

Species	Modulus of rupture (pounds per square inch)	Maximum crushing strength in compression parallel to grain (pounds per square inch)
Longleaf pine:		
Structural sizes	6,098	4,800
Small specimens	9,070	4,400
Ratio	67	109
Douglas fir:		
Structural sizes	5,983	3,495
Small specimens	8,280	4,030
Ratio	72	87
Shortleaf pine:		
Structural sizes	5,548	3,435
Small specimens	7,710	3,570
Ratio	72	96
Western larch:		
Structural sizes	4,948	3,510
Small specimens	7,251	3,696
Ratio	68	95
Loblolly pine:		
Structural sizes	5,084	2,940
Small specimens	7,870	3,340
Ratio	65	88
Tamarack:		
Structural sizes	4,556	3,230
Small specimens	6,820	3,190
Ratio	67	101
Western hemlock:		
Structural sizes	5,296	3,355
Small specimens	7,294	3,392
Ratio	73	99
Redwood:		
Structural sizes	4,472	3,882
Small specimens	6,980	3,980
Ratio	64	98
Norway pine:		
Structural sizes	3,864	2,555
Small specimens	5,173	2,504
Ratio	75	102

[a] From Forest Service *Bull.* 108, "Tests of Structural Timbers."

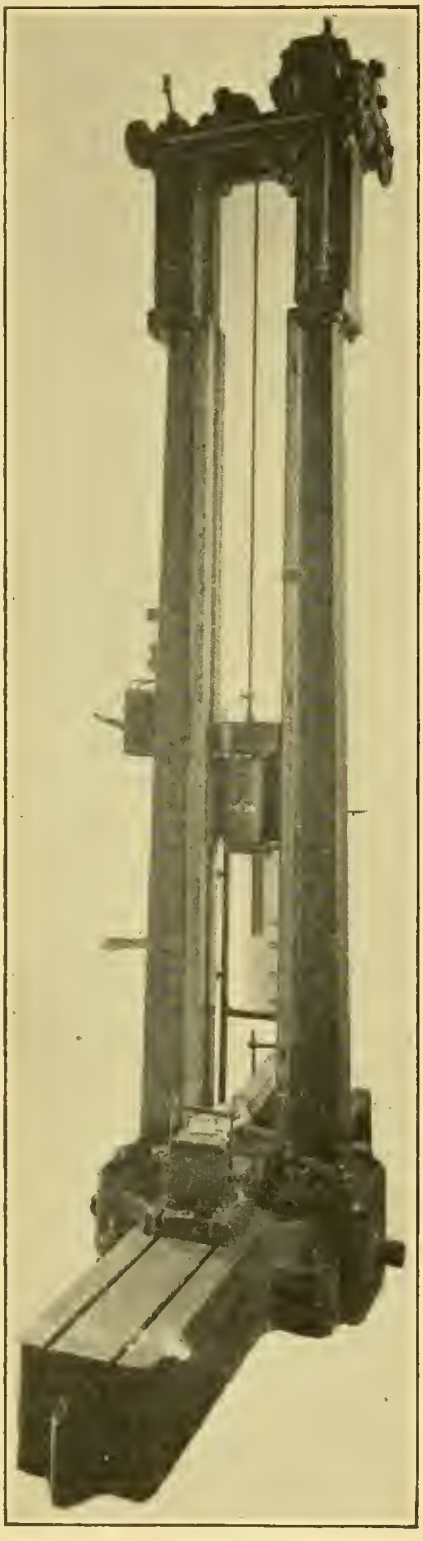


FIG. 49.—Impact testing machine. (*Courtesy, Forest Products Laboratory.*)

approximately equal static loads), and, therefore, they rank lower in toughness than the hardwoods.

The work done in breaking a certain kind of wood varies as its cubic contents irrespective of its dimensions. That is, the work done in breaking a piece 2 by 4 inches in cross-section is practically the same whether the piece is set on edge or laid flat. If laid flat, it will bend four times as much but will take only one-fourth the load.[1] Tables X and XI give the work to maximum load in inch-pounds per cubic inch for the more important native woods.

The work to maximum load, although determined from static bending tests, is a measure of the toughness of a piece of wood or its ability to withstand a shock or blow, since in order to have a high shock-resisting ability a piece of wood must possess a combination of strength and capacity to bend.

The relative shock-resisting ability of woods is also determined by subjecting a beam to direct impact. In tests made by the Forest Service this is done by dropping a 50- or 100-pound hammer on the middle of a beam, usually 2 inches square and 28 inches between supports, from successively increasing heights until the stick breaks (Fig. 49). The final height from which the hammer

[1] Theoretically this relation holds only up to the elastic limit.

is dropped indicates the relative ability of woods to resist severe shocks of short duration. Tables X and XI give values for impact tests on the more important native woods. These values give approximately the same relative rank to species as the values for work to maximum load in static bending.

40. Hardness.—The hardness of wood is a measure of its resistance to indentation. It also indicates the resistance to wear, although the latter is also influenced by cohesion of the fibers. The values for hardness given in Tables X and XI were obtained by determining the load required to imbed a 0.444-inch ball one-half its diameter into the wood. There is little difference in the hardness as measured on the radial and tangential faces, but the end hardness is greater than the side hardness. For this reason paving blocks are set on end and mallets are made so that the end grain receives the blow. The hardness of wood can be increased by drying it to almost absolute dryness and then impregnating it with molten high-grade rosin or paraffin.

41. Cleavability.—The ease with which wood splits depends more on the direction of the fibers than on any other property. Straight-grained wood usually splits more easily radially than tangentially, but in woods with interlocked grain the reverse is true. Green wood splits more easily than dry wood. The weight of wood has no consistent relation to the ease with which it splits.

42. Plasticity.—A material is said to be plastic if it can be moulded into various shapes which it will retain. Moist clay and green putty are highly plastic. Wood is more or less plastic, the plasticity increasing with the moisture content. Heating moist wood greatly increases its plasticity; therefore, in making chair backs, wheel rims, hoops, and other bent-wood articles, the wood is steamed or boiled and then bent to the desired shape in which it is held until dry.

The hardwoods are better suited for bent wood-work than the conifers, although spruce and other conifers are sometimes used for this purpose. The species which are best suited for bending purposes are ash, elm, hickory, oak, and beech, but other species, such as red gum, birch, and maple, give satisfactory results if they are not curved too much.

It is because wood is somewhat plastic that it does not check more as a result of the uneven shrinkage which takes place in drying.

43. Safe Working Stresses and Grading Rules for Structural Timbers.—The establishment of safe working stresses from data on strength tests of wood requires a consideration of (1) loss of strength due to defects, (2) the length of time the loads are to remain on timbers, (3) the variation of individual pieces from the average, and (4) to a certain extent the possibility of overloading. With a definite limitation of the size and location of defects the reduction in strength from clear material can be closely estimated. For instance, defects limited as in S2 grade described later reduce the strength to about ¾ that of the clear material.

Loads ½ to ¾ as great as those which produce failure in one hour have been shown by test to cause failure if left on for prolonged periods. Therefore, stresses for long-time loads should be kept within the elastic limit[1] which is about 9/16 of the modulus of rupture. If stresses are based on average values, provision must be made for the occasional structural timber which gives only ¾ of the average strength. Applying in addition to the factors mentioned, an actual factor of safety of say 1½ it is evident that safe working stresses for S2 structural timbers subjected to bending in dry interior construction are about one-fifth of the average modulus of rupture values for green material free from defects ($\frac{3}{4} \times \frac{9}{16} \times \frac{3}{4} \times \frac{2}{3} = \frac{27}{128}$ = about $\frac{1}{5}$).

In this connection it should be noted that no increase in strength can be planned on in seasoning large structural timbers on account of development of defects in seasoning.

Many cities and some private corporations have specified in their building codes certain strength values for different kinds of structural materials which their engineers and architects must not exceed in making calculations for the size of the materials used in construction. These strength values are obtained by applying a certain factor to the ultimate strength of materials as determined by tests. The same factor is not always used, nor are the ultimate strength values always obtained from the same authority, so that building codes vary considerably in the values given as safe working stresses. Furthermore, the working stresses often are applied without reference to the quality of the timber.

[1] For determining the fiber stress at the elastic limit the same formula is used as for modulus of rupture except that the load at the elastic limit is substituted for the maximum load in the formula.

Since the present grading of structural timbers is not based essentially on their strength, and in order to place the use of structural timbers on sound principles as far as safety and economy of material are concerned, the Forest Service has recommended, after many tests, the classification of each species into four grades according to the defects they contain, with definite working stresses for each grade. These grades, which are designated as S1, S2, S3, and S4, are intended for the following uses:

Grade S1. For use where the highest strength requirements obtain, as in railway, highway, and mill construction.

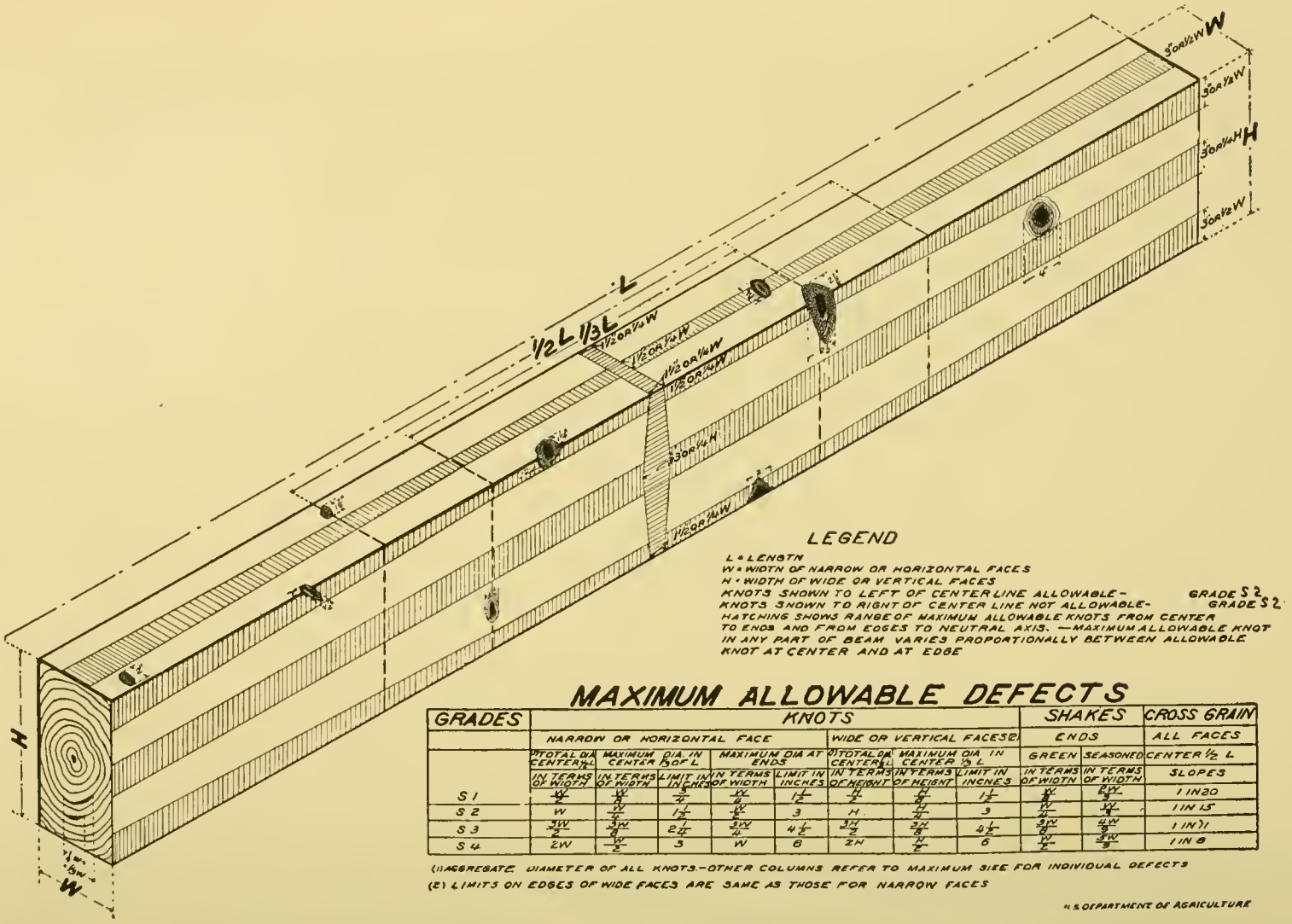
Grade S2. For general use in railway and mill construction, and whenever a select grade of structural material is desirable.

Grade S3. For general use in building construction and to a large extent in mill construction.

Grade S4. For general use in small houses, false work, and ordinary construction where stiffness is a controlling factor and where strength requirements are not so critical.

Grade S2 is the standard or basic grade of each species. In southern yellow pine and Douglas fir, the principal structural timbers, it corresponds very closely to the Select Structural Grade of the Southern Pine Association and to No. 1 Structural Grade of the West Coast Lumbermen's Association respectively. In this grade defects are allowed which reduce the strength to six-eighths that of the average clear material of the same species. In grades S1, S3, and S4 the strength is respectively seven-eighths, five-eighths, and four-eighths that of the clear material. This makes the strength of the four grades in the proportion of 7 to 6, 5, and 4. Yellow pine and Douglas fir structural timbers which meet the density requirements of the American Society of Testing Materials (explained in Art. **45**) are classed in the next higher grade than their defects would otherwise permit, the highest grade being designated as S1 (dense). Other species cannot be graded for high density so satisfactorily and, hence, this rule cannot be applied to them. Exceptionally light pieces of all species are classed in the grade next below that determined by their defects alone.

The rules as given at the conclusion of this chapter relative to the permissible defects in each grade are proposed by the Forest Service. Figure 50 illustrates the application of these rules. There is a simple mathematical relation of 1 to 2, 3, and


L
1/2 L 1/3 L
1½ OR ¼ W
1½ OR ¼ W
1½ OR ¼ W
1½ OR ¼ W
1½ OR ¼ W
3 OR ½ W
3 OR ½ W
3 OR ¼ H
3 OR ½ W
H
W
¼ W OR ⅓ W
LEGEND
L = LENGTH
W = WIDTH OF NARROW OR HORIZONTAL FACES
H = WIDTH OF WIDE OR VERTICAL FACES
KNOTS SHOWN TO LEFT OF CENTER LINE ALLOWABLE— GRADE S2
KNOTS SHOWN TO RIGHT OF CENTER LINE NOT ALLOWABLE— GRADE S2
HATCHING SHOWS RANGE OF MAXIMUM ALLOWABLE KNOTS FROM CENTER TO ENDS AND FROM EDGES TO NEUTRAL AXIS. —MAXIMUM ALLOWABLE KNOT IN ANY PART OF BEAM VARIES PROPORTIONALLY BETWEEN ALLOWABLE KNOT AT CENTER AND AT EDGE

MAXIMUM ALLOWABLE DEFECTS

GRADES	KNOTS								SHAKES		CROSS GRAIN
	NARROW OR HORIZONTAL FACE					WIDE OR VERTICAL FACES(2)			ENDS		ALL FACES
	(1) TOTAL DIA. CENTER ½ L	MAXIMUM DIA. IN CENTER ⅓ OF L		MAXIMUM DIA. AT ENDS		(1) TOTAL DIA. CENTER ½ L	MAXIMUM DIA. IN CENTER ⅓ L		GREEN	SEASONED	CENTER ½ L
	IN TERMS OF WIDTH	IN TERMS OF WIDTH	LIMIT IN INCHES	IN TERMS OF WIDTH	LIMIT IN INCHES	IN TERMS OF HEIGHT	IN TERMS OF HEIGHT	LIMIT IN INCHES	IN TERMS OF WIDTH	IN TERMS OF WIDTH	SLOPES
S1	¼W	⅛W	¾	⅛W	1½	½	¼	1½	⅛W	⅓W	1 IN 20
S2	W	⅓W	1½	¼W	3	H	⅓	3	¼W	⅛W	1 IN 15
S3	¾W	⅜W	2¼	¾W	4½	¾H	⅜H	4½	⅜W	⅓W	1 IN 11
S4	2W	½	3	W	6	2H	½	6	½	⅔W	1 IN 8

(1) AGGREGATE DIAMETER OF ALL KNOTS.—OTHER COLUMNS REFER TO MAXIMUM SIZE FOR INDIVIDUAL DEFECTS
(2) LIMITS ON EDGES OF WIDE FACES ARE SAME AS THOSE FOR NARROW FACES

U. S. DEPARTMENT OF AGRICULTURE

FIG. 50.—Illustration of application of grading rules to beams of the S2 grade.

4 between the sizes of the defects in the different grades which makes it easy to remember the rules.

The permissible working stresses for the S2 grade are given in Table XV. Allowable stresses for the other grades can easily be computed from this table.

Since moisture affects the strength of wood fiber and also influences its susceptibility to decay, allowable stresses are given for three different locations except for shearing stresses and elasticity which are only slightly affected by moisture, namely, damp or wet; outside, not in contact with soil; and inside, dry location. No attempt is made, however, to grade the timbers or to assign permissible stresses to them in accordance with their durability. Where long life is desired in damp locations, properly preserved timbers or naturally durable species with little or no sapwood should be selected.

Since the modulus of elasticity of low grades is only slightly less than that of high grades no distinction is made as to the stiffness of the various grades. For light construction in which stiffness is of more importance than breaking strength, the lower grades can often be used to advantage because of their lower cost.

GENERAL RULES

Light-weight Material.—All exceptionally light-weight pieces in any species shall be lowered one grade.

Dense Material.—Southern yellow pine and Douglas fir which will classify as dense under the rules of the American Society for Testing Materials for these species take the stress of the next higher grade.

Knots and Knot Holes.—The measurement of knots or knot holes is made on the section of the knot or knot hole appearing on the surface in question. The diameter of a knot on the narrow or horizontal face shall be taken as the width of the knot between lines parallel to the edges of the timber. On the wide or vertical face the smallest dimension of a knot shall be taken. Knots on the edge of wide faces are limited to the same size as on the adjacent portion of the narrow faces. Cluster knots occurring on any face in any part of a beam shall cause its rejection except when specifically permitted. The diameter of cluster knots shall be measured between lines enclosing the cluster. Unsound or

decayed knots in which the decay does not exceed the diameter of the knots are limited as are sound knots.

Checks, Shakes, and Splits.—Checks, or combination of checks with shakes, which would reduce the strength to a greater extent than the allowable round shake shall not be permitted. Restrictions on shakes are given in each grade. The width of shakes shall be taken as the distance between lines parallel to the vertical edges of a timber. Splits shall be graded as checks or shakes.

Decay.—All grades shall contain only sound wood unless decay is specifically permitted.

Sapwood.—Unless otherwise specified any amount of sapwood is permitted in all grades.

Holes.—Dog, picaroon, bird, insect, and rafting-pin holes shall be limited for each grade in the same manner as knot holes.

Other Defects.—Defects other than knots, knot holes, decay, shakes, checks, splits, and cross grain are omitted from these rules, as they are limited ordinarily by considerations other than strength and should be restricted when necessity requires by application of standard yard lumber rules to faces.

Method of Measuring Defects.—Figure 50 illustrates the method of measuring the various kinds of knots on the horizontal and vertical faces, and the method of measuring shakes on the ends. The gradual increase in size of the allowable knots from the center one-third of length to end and from edge to center of the wide face is also illustrated. The table accompanying the figure gives in condensed form the defect limitations of all grades.

Select (S2) Grade (Base Grade)

(For Heavy Construction Work)

Knots—General.—The sum of the diameters of all knots within the center half of the length of a beam shall not exceed the width of the face on which they occur.

Narrow or Horizontal Faces.—A knot hole or sound knot on the narrow or horizontal faces and in the center third of the length of a beam shall not exceed in diameter one-fourth the width of the face (maximum knot 1½ inches). Outside the center one-third of the length, the size of a knot may increase gradually towards the end to one-half the width of the face (maximum knot 3 inches).

Wide or Vertical Faces.—Knot holes or sound knots on the edges of the wide faces shall be limited to the same size as on the adjacent portion of the narrow faces, but a knot may increase gradually in size towards the center of height to one-fourth the width of the face (maximum knot 3 inches).

Shakes.—Round or ring shakes showing on the end of a timber shall not measure more than one-fourth of the width in green material, nor more than one-third of the width in seasoned material.

Cross Grain.—Within the center half of the length of a beam the slope in grain shall not exceed 1 in 15.

Extra Select (S1) Grade

(For Most Exacting Construction Purposes)

Knots—General.—The sum of the diameters of all knots within the center half of the length of a beam shall not exceed one-half the width of the face on which they occur.

Narrow or Horizontal Faces.—A knot hole or sound knot on the narrow or horizontal faces and in the center third of the length of a beam shall not exceed in diameter one-eighth the width of the face (maximum knot ¾ inch). Outside the center one-third of the length, the size of a knot may increase gradually towards the end to one-fourth the width of the face (maximum knot 1½ inches).

Wide or Vertical Faces.—Knot holes or sound knots on the edge of the wide faces shall be limited to the same size as on the adjacent portion of the narrow faces, but a knot may increase gradually in size towards the center of height to one-eighth the width of the face (maximum knot 1½ inches).

Shakes.—Round or ring shakes showing on the end of a timber shall not measure more than one-eighth of the width in green material, nor more than two-ninths of the width in seasoned material.

Cross Grain.—Within the center half of the length of a beam the slope in grain shall not exceed 1 in 20.

Standard (S3) Grade

(For General Building Use)

Knots—General.—The sum of the diameters of all knots within the center half of the length of a beam shall not exceed

one and one-half times the width of the face on which they occur.

Narrow or Horizontal Faces.—A knot hole or sound knot on the narrow or horizontal faces and in the center third of the length of a beam shall not exceed in diameter three-eighths the width of the face (maximum knot 2¼ inches). Outside the center one-third of the length, the size of a knot may increase gradually towards the end to three-fourths the width of the face (maximum knot 4½ inches).

Wide or Vertical Faces.—Knot holes or sound knots on the edge of the wide face shall be limited to the same size as on the adjacent portion of the narrow face, but the knot may increase gradually in size towards the center of height to three-eighths the width of the face (maximum knot 4½ inches).

Shakes.—Round or ring shakes showing on the end of a timber shall not measure more than three-eighths the width in green material, nor more than four-ninths the width in seasoned material.

Cross Grain.—Within the center half of the length of a beam the slope in grain shall not exceed 1 in 11.

Common (S4) Grade

(For Small House Construction)

Decay.—A beam may contain heart rot not to exceed one-tenth the area of the cross-section of the piece.

Knots—General.—The sum of the diameters of all knots within the center half of the length of a beam shall not exceed twice the width of the face on which they occur. Unsound or decayed knots to one-half the size of the sound knots are permitted in this grade. Cluster knots of the same diameter as sound knots are permitted in this grade.

Narrow or Horizontal Faces.—A knot hole or sound knot on the narrow or horizontal faces and in the center third of the length of a beam shall not exceed in diameter one-half the width of the face (maximum knot 3 inches). Outside the center one-third of the length the size of knots may increase gradually towards the end where it may be equal to the width of the face (maximum knot 6 inches).

Wide or Vertical Faces.—Knot holes or sound knots on the edges of the wide faces shall be limited to the same size as on

the adjacent portion of the narrow face, but the knot may increase gradually in size towards the center of the height to one-half the width of the face (maximum knot 6 inches).

Shakes.—Round or ring shakes showing on the end of a timber shall not measure more than one-half of the width in green material, nor more than five-ninths the width in seasoned material.

Cross Grain.—Within the center half of the length of a beam the slope in grain shall not exceed 1 in 8.

TABLE XV.—WORKING STRESSES PERMISSIBLE FOR STRUCTURAL TIMBERS OF SELECT (S2) GRADE[a]

(Pounds per square inch)

Species	Bending					Compression					
	Allowable stress in extreme fiber for Select (S2) grade			Allowable horizontal shear stress Select (S2) grade, all locations	Allowable modulus of elasticity for all grades, all locations	Allowable stress parallel to grain "Short Columns"[b] for Select (S2) grade			Allowable stress perpendicular to grain for all grades		
	Damp or wet location (docks, piling, and sills)	Outside, not in contact with soil (bridges and open sheds)	Under shelter in dry location (factories and warehouses)			Wet location	Dry outside location	Dry inside location	Wet location	Dry outside location	Dry inside location
Ash, black	800	900	1,000	90	1,100,000	500	550	650	150	200	300
Commercial white (green, Biltmore, white)	1,000	1,200	1,400	125	1,500,000	900	1,000	1,100	300	375	500
Aspen and largetooth aspen	500	650	800	80	900,000	450	550	700	100	125	150
Basswood	500	650	800	80	900,000	450	550	700	100	125	150
Beech	1,000	1,300	1,500	125	1,600,000	900	1,100	1,200	300	375	500
Birch, paper	600	750	900	80	1,000,000	450	550	650	100	150	200
Yellow and sweet	1,000	1,300	1,500	120	1,600,000	900	1,100	1,200	300	375	500
Cedar, Alaska	800	900	1,000	90	1,100,000	650	750	800	150	200	250
Western red	750	800	900	80	1,000,000	650	700	700	125	150	200
Northern and southern white	600	650	750	70	800,000	450	500	550	100	140	175
Port Orford	900	1,000	1,100	100	1,200,000	750	825	900	150	200	250
Chestnut	700	850	950	90	1,000,000	600	700	800	150	200	300
Cottonwood, common and black	500	650	800	80	900,000	450	550	700	100	125	150
Cypress, bald	900	1,100	1,300	100	1,400,000	800	1,000	1,100	225	250	350
Douglas fir (western Washington and Oregon)[c]	1,000	1,300	1,500	90	1,600,000	850	1,000	1,100	200	225	325
(Rocky Mountain type)	700	900	1,100	85	1,200,000	700	800	800	200	225	275
Elm, cork	1,000	1,300	1,500	125	1,300,000	900	1,100	1,200	300	375	500
Slippery and white	800	900	1,100	100	1,200,000	650	750	800	125	175	250
Fir, balsam	600	750	900	70	1,000,000	500	600	700	100	125	150
Commercial white (white, noble, grand)	800	900	1,100	70	1,200,000	650	750	800	150	200	300

Gum, black and cotton	800	900	1,100	100	1,200,000	650	750	800	150	200	300
Red	800	900	1,100	100	1,200,000	650	750	800	150	200	300
Hemlock, western	900	1,100	1,300	75	1,400,000	800	900	900	200	225	300
(Eastern)	800	900	1,000	70	1,100,000	600	700	700	200	225	300
Hickory (true and pecan)	1,200	1,500	1,900	140	1,800,000	1,000	1,200	1,500	350	400	600
Larch, western	900	1,100	1,200	100	1,300,000	800	1,000	1,100	200	275	325
Maple, sugar and black	1,000	1,300	1,500	150	1,600,000	900	1,100	1,200	300	375	500
Red and silver	700	900	1,000	100	1,100,000	600	700	800	200	250	350
Oak, commercial red and white	1,000	1,200	1,400	125	1,500,000	800	900	1,000	300	375	500
Pine, southern yellow[c]	1,000	1,300	1,500	110	1,600,000	850	1,000	1,100	200	225	325
White, sugar, western white, western yellow	750	800	900	85	1,000,000	650	750	750	125	150	250
Norway	800	1,000	1,100	85	1,200,000	700	800	800	150	175	300
Poplar, yellow	800	900	1,000	80	1,100,000	600	700	800	125	150	250
Redwood	800	1,000	1,200	70	1,200,000	750	900	1,000	125	150	250
Spruce, red, white, Sitka	800	900	1,100	85	1,200,000	650	750	800	125	150	250
Engelmann	500	650	750	70	800,000	450	550	600	100	140	175
Sycamore	800	900	1,100	80	1,200,000	650	750	800	150	200	300
Tamarack (eastern)	900	1,100	1,200	95	1,300,000	800	900	1,000	200	225	300

[a] Working stresses for Extra Select (S1), Extra Select (S1) Dense, Standard (S3), and Common (S4) grades are obtained by multiplying the basic stress by 7/6, 8/6, 5/6, and 4/6 respectively

[b] The influence of knots on compressive strength of columns of constant cross-section decreases as the length increases. When the length reaches 30 times the least dimension, knots such as are allowable in Select (S2) timbers have no effect on the strength as a column.

[c] The working stresses of any grade of timbers of Douglas fir and southern yellow pine which meet the density requirements of the American Society of Testing Materials shall be increased one-sixth the allowable stress given in the table for the basic or Select (S2) grade.

CHAPTER V

FACTORS AFFECTING THE STRENGTH OF WOODEN MEMBERS

Wood varies considerably in strength; therefore, certain precautions must be observed in selecting wooden members which will be subjected to severe stresses. Not only is it necessary that such pieces be of the proper kind and dimensions, but also that the quality and condition of the wood be considered. Timber grows under variations in soil fertility, soil moisture, climate, and available light; hence, it is not surprising that differences in strength may be found in green timbers of the same species and even within the same tree. Furthermore, seasoning usually increases the strength of wood, whereas decay and other defects are well-known sources of weakness.

The quality of wood can often be determined fairly accurately by visual inspection or by simple tests, thus making it possible to eliminate to a large extent weak and defective pieces.

44. Size and Shape of Piece.—The strength of a wooden member varies with the dimensions as has been explained in the previous chapter. The strength of the wood fibers or the strength per unit section is, of course, independent of the dimensions of the whole piece, except that the size of the piece is a factor influencing the strength through defects which develop in seasoning.

45. Density.—From many thousand tests made at the Forest Products Laboratory it has been found that there is a fairly definite relation between the strength of wood free from weakening defects and its dry weight (density). The maximum strength in compression parallel to the grain and the stiffness (modulus of elasticity) vary directly as the density. That is, in general, a piece twice as heavy as another ranks about twice as high in these properties. The modulus of rupture, the fiber stress at the elastic limit in static bending, and shearing strength parallel to the grain increase slightly more rapidly than the density, and the shock-resisting ability, hardness, and fiber stress at the elastic limit in compression perpendicular to the grain vary approximately as the square of the density. That is, a piece of

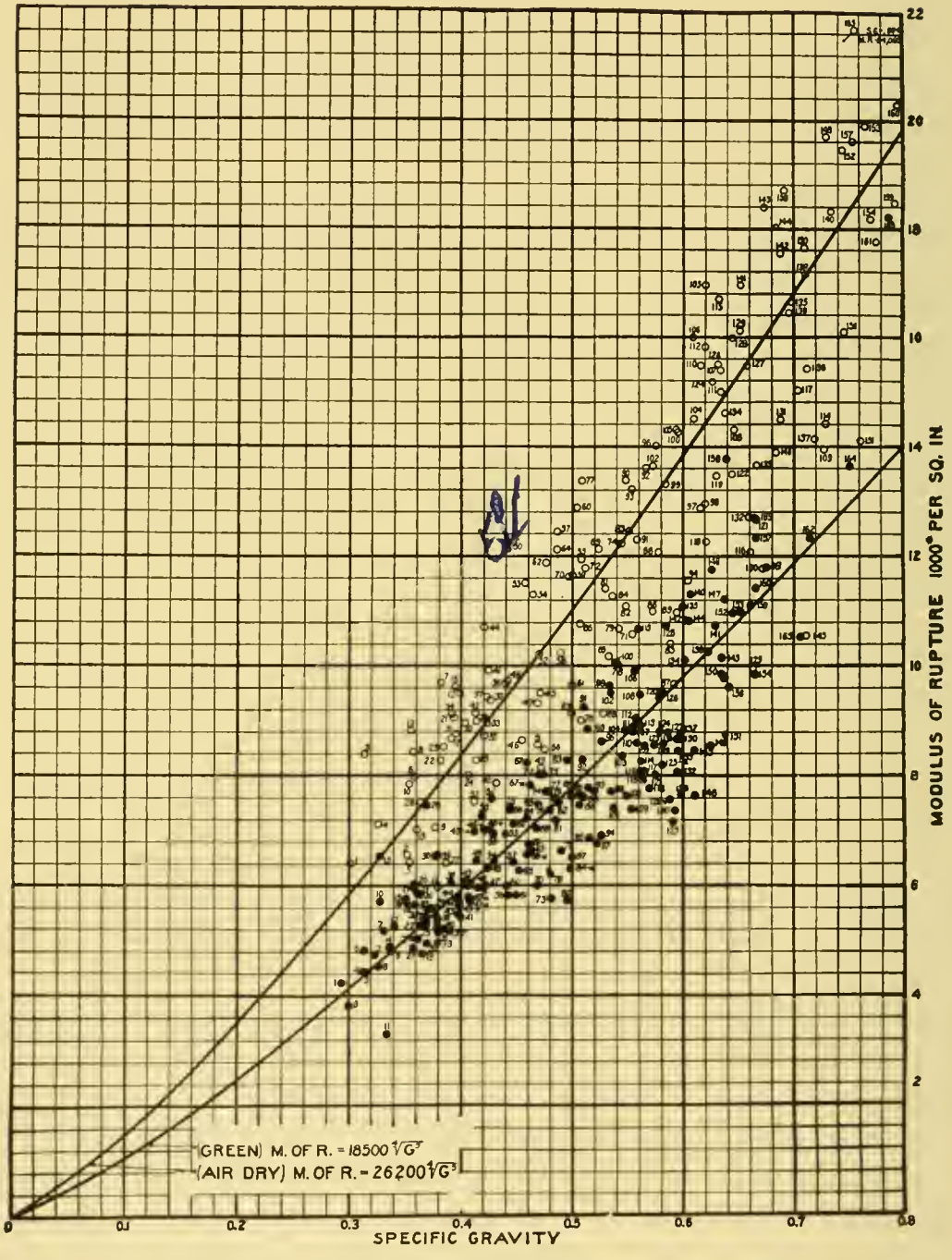


FIG. 51.—Relation of modulus of rupture to specific gravity. See pages 125 and 126 for legend. (*Courtesy, Forest Products Laboratory.*)

List of Species and Reference Numbers for Fig. 51

Hardwoods

Species	Locality	Reference No.
Alder, red	Washington	30
Ash:		
Bitmore	Tennessee	91
Black	Michigan	60
Black	Wisconsin	70
Blue	Kentucky	99
Green	Louisiana	93
Green	Missouri	100
Pumpkin	Missouri	79
White	Arkansas	106
White	New York	128
White	West Virginia	83
Aspen	Wisconsin	23
Largetooth	Wisconsin	20
Basswood	Pennsylvania	12
Basswood	Wisconsin	5
Beech	Indiana	110
Beech	Pennsylvania	98
Birch:		
Paper	Wisconsin	73
Sweet	Pennsylvania	129
Yellow	Pennsylvania	107
Yellow	Wisconsin	103
Buckeye, yellow	Tennessee	9
Buckthorn, cascara	Oregon	84*a*
Butternut	Tennessee	27
Butternut	Wisconsin	21
Chinquapin, western	Oregon	46*b*
Cherry:		
Black	Pennsylvania	72
Wild red	Tennessee	24
Chestnut	Maryland	46
Chestnut	Tennessee	40
Cottonwood, black	Washington	6
Cucumber tree	Tennessee	59
Dogwood:		
Flowering	Tennessee	151
Western	Oregon	125*a*
Elder, pale	Oregon	69*a*
Elm:		
Cork	Wisconsin, Marathon County.	126
Cork	Wisconsin, Rusk County.	120
Slippery	Indiana	102
Slippery	Wisconsin	74
White	Pennsylvania	55
White	Wisconsin	53
Greenheart		165
Gum:		
Black	Tennessee	68
Blue (Eucalyptus)	California	147
Cotton	Louisiana	76
Red	Missouri	54
Hackberry	Indiana	90
Hackberry	Wisconsin	78
Haw, pear	Wisconsin	146
Hickory:		
Big shellbark	Mississippi	135
Big shellbark	Ohio	154
Bitternut	Ohio	139
Mockernut	Mississippi	144
Mockernut	Pennsylvania	159
Mockernut	West Virginia	155
Nutmeg	Mississippi	112
Pignut	Mississippi	148
Pignut	Ohio	157
Hickory—*Continued.*		
Pignut	Pennsylvania	160
Pignut	West Virginia	161
Shagbark	Mississippi	140
Shagbark	Ohio	152
Shagbark	Pennsylvania	143
Shagbark	West Virginia	153
Water	Mississippi	141
Holly, American	Tennessee	87
Hornbeam	Tennessee	149
Laurel, mountain	Tennessee	145
Locust:		
Black	Tennessee	158
Honey	Indiana	162
Madrona	California	101
Madrona	Oregon	128*a*
Magnolia	Louisiana	66
Maple:		
Oregon	Washington	58
Red	Pennsylvania	69
Red	Wisconsin	92
Silver	Wisconsin	56
Sugar	Indiana	104
Sugar	Pennsylvania	108
Sugar	Wisconsin	124
Oak:		
Bur	Wisconsin	125
California black	California	80
Canyon live	California	163
Chestnut	Tennessee	121
Cow	Louisiana	133
Laurel	Louisiana	116
Post	Arkansas	130
Post	Louisiana	137
Red	Arkansas	119
Red	Indiana	118
Red	Louisiana	117
Red	Tennessee	97
Highland Spanish	Louisiana	94
Lowland Spanish	Louisiana	142
Swamp white	Indiana	150
Tanbark	California	115
Water	Louisiana	111
White	Arkansas	132
White	Indiana	138
White	Louisiana, Richland Parish.	136
White	Louisiana, Winn Parish.	131
Willow	Louisiana	109
Yellow	Arkansas	122
Yellow	Wisconsin	105
Osage orange	Indiana	164
Poplar, yellow (tulip tree)	Tennessee	35
Rhododendron, great	Tennessee	85
Sassafras	Tennessee	51
Serviceberry	Tennessee	156
Silverbell tree	Tennessee	49
Sourwood	Tennessee	89
Sumac, staghorn	Wisconsin	61
Sycamore	Indiana	63
Sycamore	Tennessee	65
Umbrella, Fraser	Tennessee	45
Willow:		
Black	Wisconsin	11
Western black	Oregon	43*a*
Witch hazel	Tennessee	114

List of Species and Reference Numbers for Fig. 51—*Continued*

Conifers

Species	Locality	Reference No.
Cedar:		
Incense	California	26
Western red	Montana	2
Western red	Washington	10
White	Wisconsin	1
Cypress, bald	Louisiana	62
Douglas fir	California	45*a*
Douglas fir	Oregon	67*a*
Douglas fir	Washington, Chehalis County.	46*a*
Douglas fir	Washington, Lewis County	75
Douglas fir	Washington and Oregon	67
Douglas fir	Wyoming	84
Fir:		
Alpine	Colorado	4
Amabilis	Oregon	39
Amabilis	Washington	18
Balsam	Wisconsin	14
Grand	Montana	36
Noble	Oregon	16
White	California	17
Hemlock:		
Black	Montana	47
Eastern	Tennessee	52
Eastern	Wisconsin	15
Western	Washington	50
Larch, western	Montana	84
Larch, western	Washington	64
Pine:		
Cuban	Florida	127
Jack	Wisconsin	43
Jeffrey	California	33
Loblolly	Florida	88
Lodgepole	Colorado	31
Lodgepole	Montana, Gallatin County.	35*a*
Lodgepole	Montana, Granite County.	41*a*
Pine—*Continued.*		
Lodgepole	Montana, Jefferson County.	40*a*
Lodgepole	Wyoming	34
Longleaf	Florida	123
Longleaf	Louisiana, Lake Charles.	113
Longleaf	Louisiana, Tangipahoa Parish.	96
Longleaf	Mississippi	95
Norway	Wisconsin	57
Pitch	Tennessee	71
Pond	Florida	86
Shortleaf	Arkansas	77
Sugar	California	22
Table Mountain	Tennessee	82
Western white	Montana	42
Western yellow	Arizona	19
Western yellow	California	37
Western yellow	Colorado	41
Western yellow	Montana	32
White	Wisconsin	25
Redwood	California, Albion.	28
Redwood	California, Korbel.	13
Spruce:		
Engelmann	Colorado, Grand County.	8
Engelmann	Colorado, San Miguel County.	3
Red	New Hampshire	44
Red	Tennessee	29
White	New Hampshire.	7
White	Wisconsin	38
Tamarack	Wisconsin	81
Yew, western	Washington	134

wood with a density, or specific gravity, 20 per cent greater than that of another may be expected to be 25 per cent stronger in bending and 45 to 50 per cent tougher and harder. The average relation of various strength properties to density for numerous species is shown in Figs. 51 and 52. In the equation of each curve, F is the numerical value of each property and G the specific gravity. Thus, the equation of work to maximum load, $F = 42.7G^2$, means that the work to maximum load in inch pounds per cubic inch for any piece of clear green wood may be expected to be approximately 42.7 times the square of the specific gravity of that wood.

The relations expressed in Figs. 51 and 52 are obtained from averages for many different species. In any individual species the relation between specific gravity and strength usually follows

a slightly higher power curve, as indicated for the modulus of rupture of white ash in Fig. 53. Hence, it is very essential to discard all light pieces of a species for purposes where strength is necessary, especially toughness, since it varies approximately as the square of the density.[1]

An exception to an otherwise fairly definite relation between density and strength is found in the wood formed on the under-

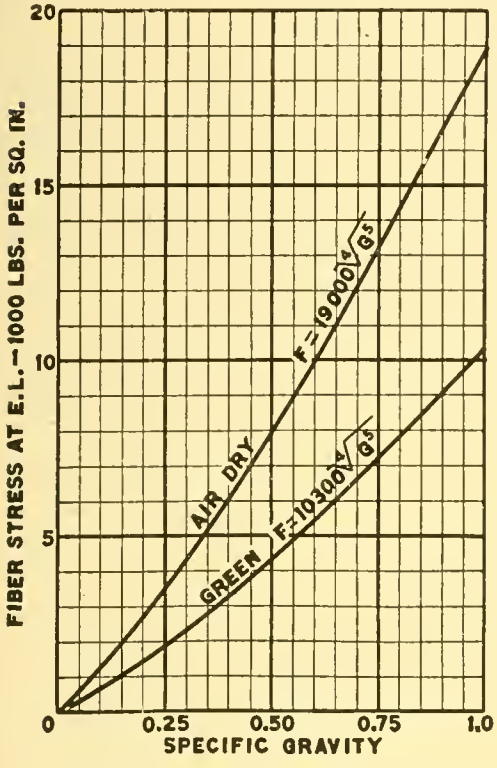


FIG. 52A.—Static bending—fiber stress at elastic limit.

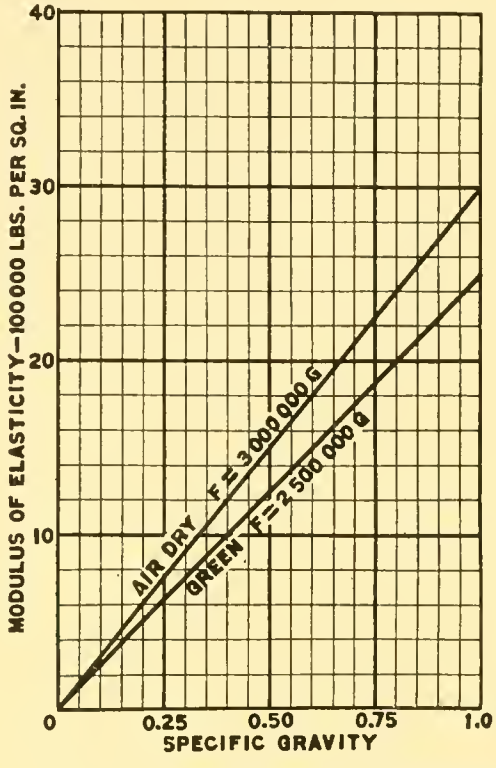


FIG. 52B.—Static bending—modulus of elasticity.

FIG. 52.—Curves showing the relation of various strength properties to the specific gravity of wood.

side of leaning coniferous trees. Such trees usually show eccentric growth in cross-section, the rings being wider on the underside. The wide part of each ring is composed mostly of summerwood, but the summerwood is not so dense, dark, and horn-like as in normal wood (Fig. 54). This wood, which is called "compression wood," is not so strong in bending as might be expected from its weight. Lumber containing compression wood should not be used for purposes where strength is essential.

[1] For further details on the relation of strength to density see, NEWLIN, J. A. and WILSON, T. R. C., "The Relation of the Shrinkage and Strength Properties of Wood to Its Specific Gravity," from which Figs. 51 and 52 were taken. United States Department of Agriculture *Bull.* 676.

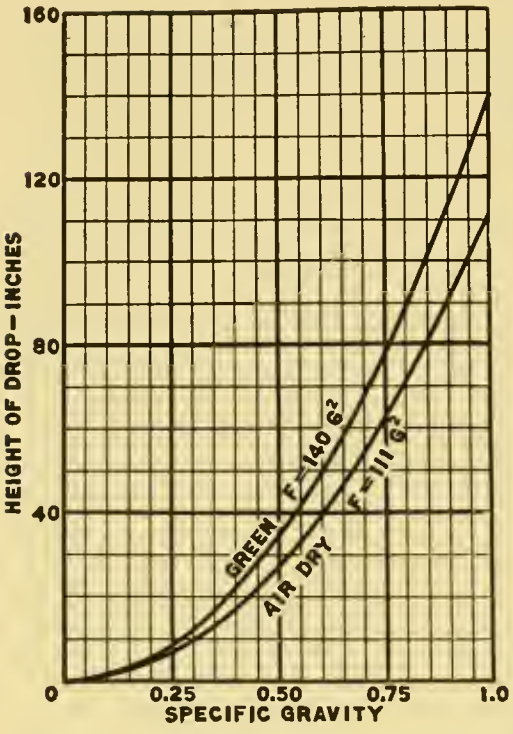


FIG. 52*C*.—Impact bending—height of drop of 50-pound hammer causing complete failure.

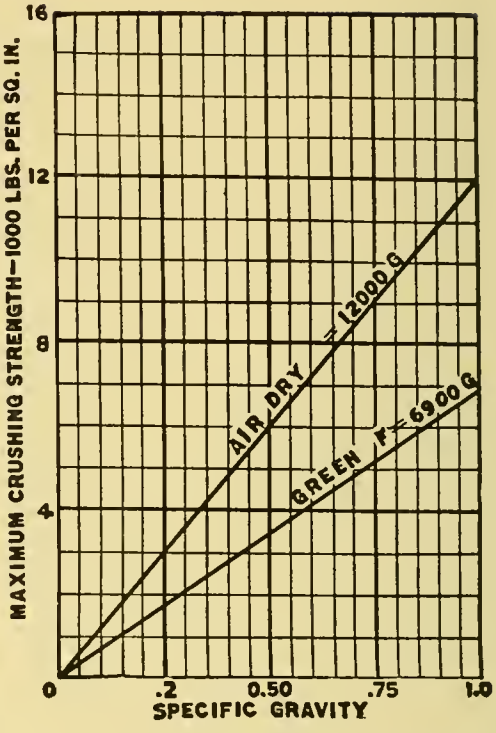


FIG. 52*D*.—Compression parallel to grain, maximum crushing strength.

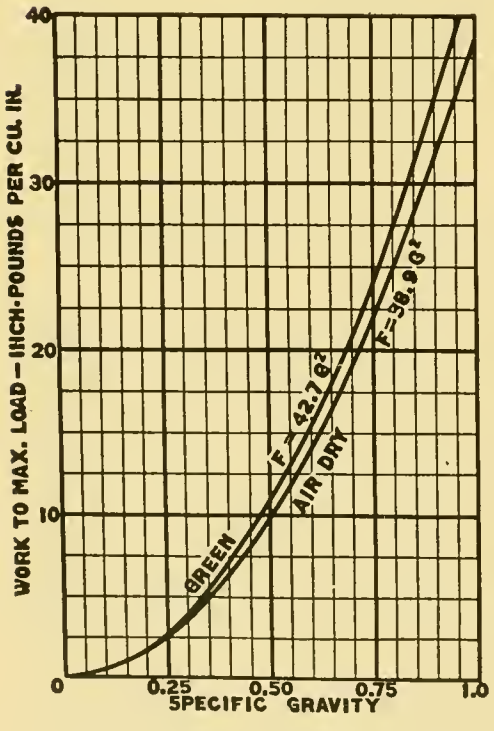


FIG. 52*E*.—Static bending—work to maximum load.

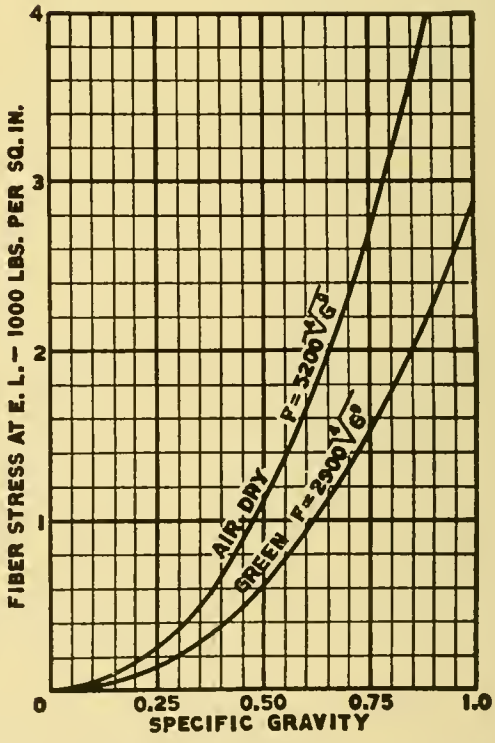


FIG. 52*F*.—Compression perpendicular to grain, fiber stress at elastic limit.

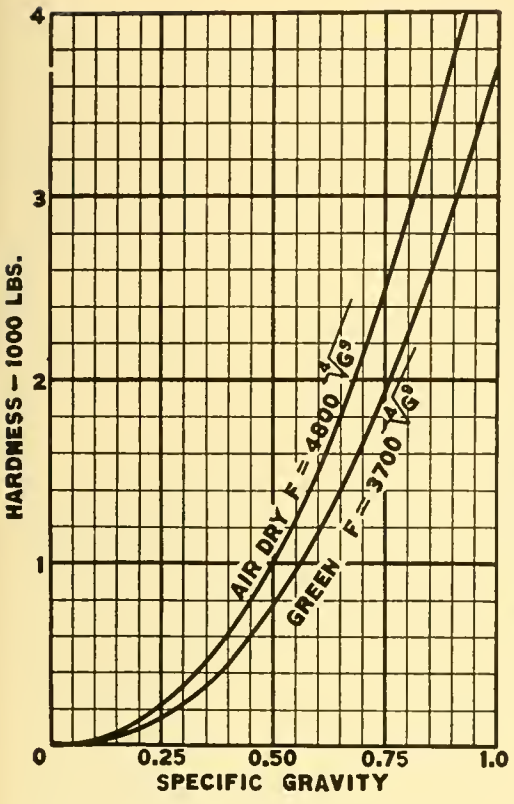


FIG. 52*G*.—Hardness—end surface.

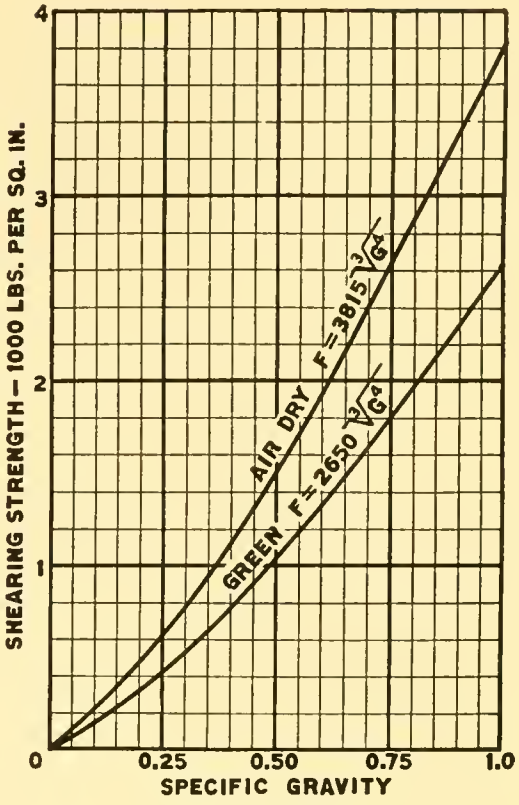


FIG. 52*H*.—Shearing strength parallel to grain.

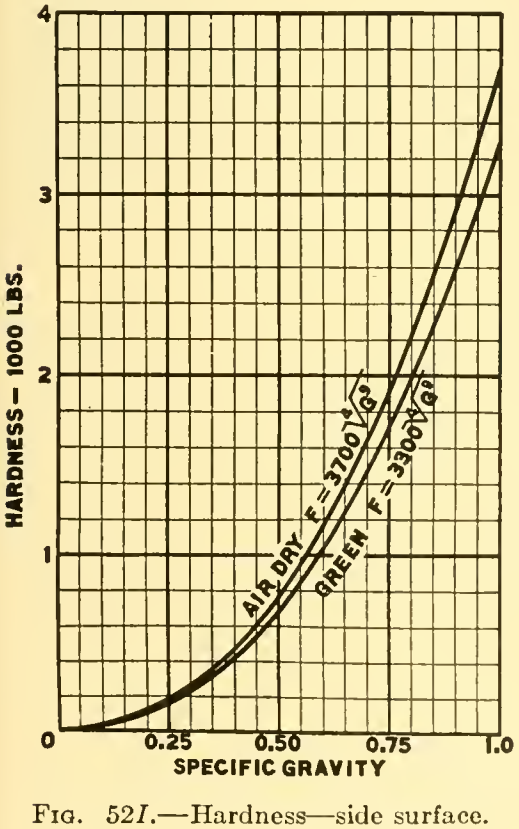


FIG. 52*I*.—Hardness—side surface.

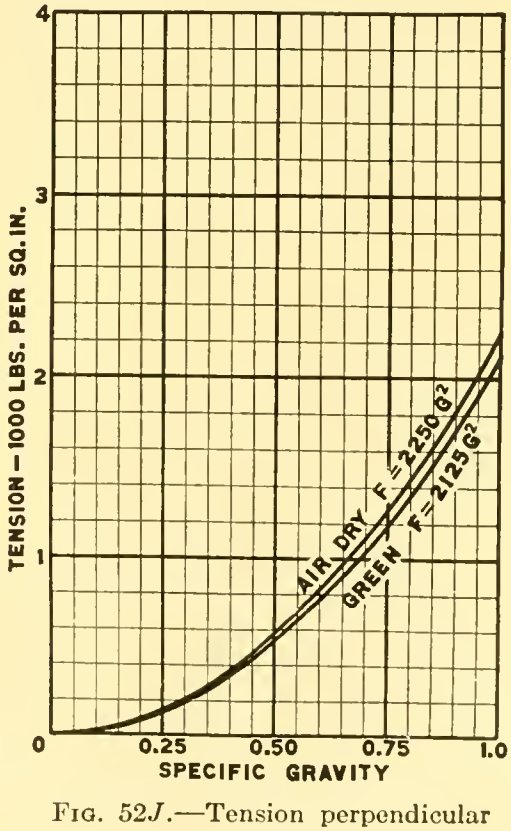


FIG. 52*J*.—Tension perpendicular to grain.

Tests made at the Forest Products Laboratory on yellow pine normal wood and compression wood having average specific gravities of 0.56 and 0.67 respectively showed that in spite of the greater specific gravity of the compression wood its modulus of rupture was only 77 per cent that of the normal wood, although in maximum crushing strength parallel to the grain the compression wood ranked 10 per cent higher.

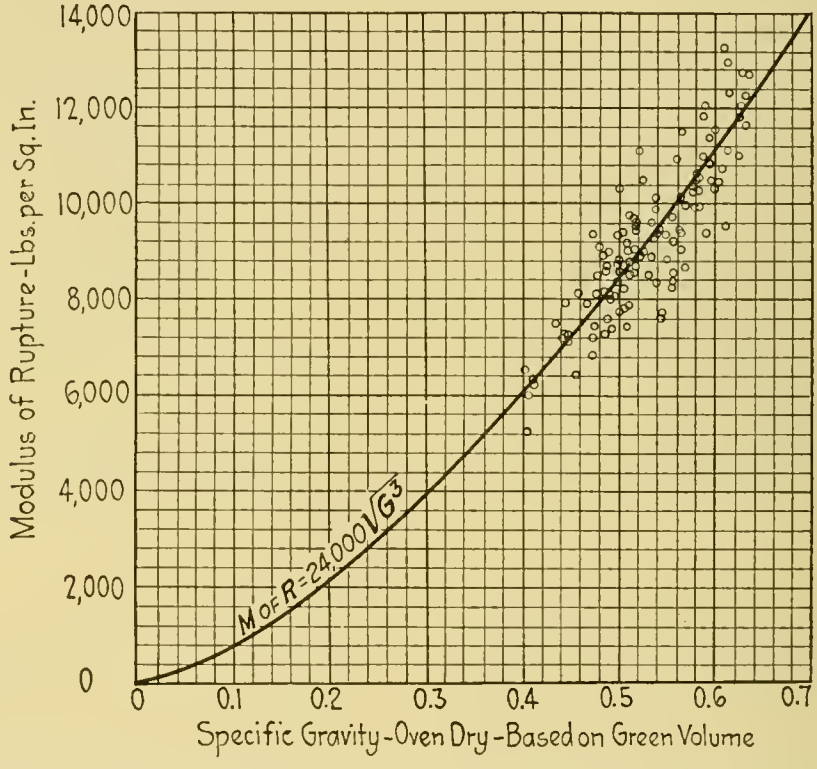


FIG. 53.—Relation of modulus of rupture to specific gravity based on small, clear specimens of white ash in a green condition.

Estimation of Density.—Since the strength of wood varies as the density, it is highly desirable to have some means of readily determining its density. The dry weight or specific gravity, as already stated, is a good criterion as to the density and hence the strength of wood. In fact, outside of an actual test it is the best indication of the strength of pieces without weakening defects. But it is not always possible to determine quickly what the dry weight is because the wood may contain considerable moisture which must first be evaporated, or the necessary apparatus may not be available.

The hardness of wood, as indicated by resistance to cutting across the grain, is a help in estimating the density of a piece of wood, but this test cannot be used in commercial grading because

it cannot be properly defined. The hardness, like the weight, is influenced by moisture content but not to so great an extent.

The character of the annual rings as seen on the end grain is a fairly reliable indication of the density of some species, but it cannot be applied with equal satisfaction to all woods. In the conifers and ring-porous hardwoods, in which there is more or less of a decided contrast between springwood and summerwood, the proportion of the hard summerwood to the softer, more porous springwood is a measure of the relative density of different pieces of the same species. However, since the summerwood

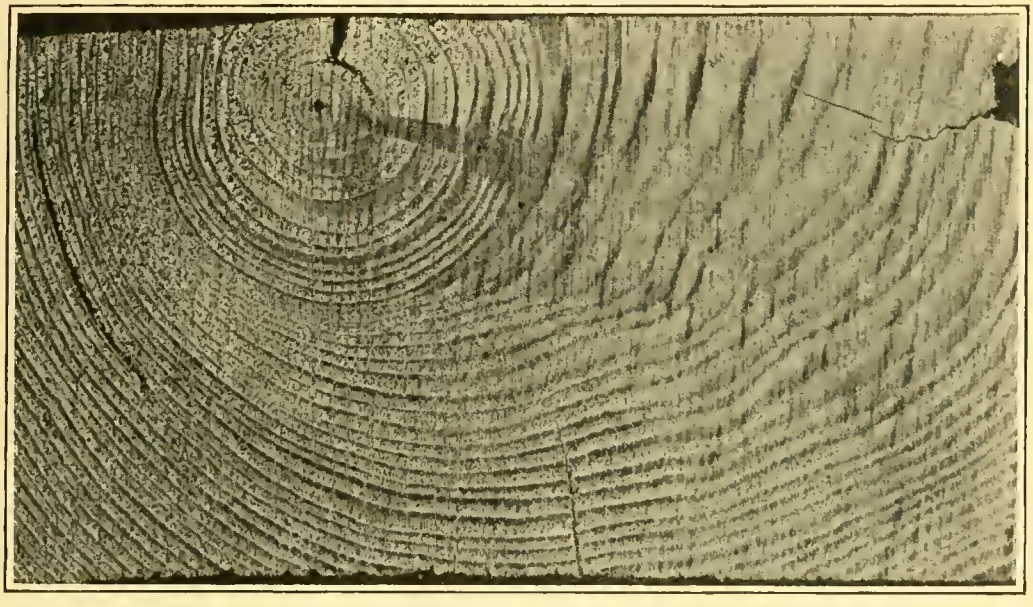


FIG. 54.—Cross-section of southern yellow pine timber containing compression wood (upper right-hand quarter).

itself may vary considerably in density, its nature must also be taken into consideration. For example, two pieces of pine may contain the same proportion of summerwood in the annual rings, but if the summerwood of one is denser than that of the other a corresponding difference in strength may be expected. The density of the summerwood can be estimated from its color, luster, and hardness when cut with a knife across the grain.

In conifers, wide rings and very narrow rings, as a rule, contain a smaller proportion of summerwood than rings of average width, as is shown in Fig. 55. Therefore, so-called second-growth conifers because of their vigorous growth, resulting in wide rings with a small proportion of summerwood, usually are inferior in strength to virgin growth timber. The center portion of many

conifers is not so strong as the wood further from the center because of the wide rings with a small proportion of summerwood usually found near the center. In many old coniferous trees the outer portion in which the rings are very narrow and the proportion of summerwood small, as a rule, is not so strong as the wood further in. This, probably, is responsible for the common but erroneous belief that sapwood is essentially weaker than heartwood.

In the grading of southern yellow pine and Douglas fir timbers the width of the rings and the proportion of summerwood can be used in determining the quality of the wood. Specifications for

FIG. 55.—Southern yellow pine with less than 30 per cent summerwood in narrow (*a*) and wide-ringed (*c*) material, and over 50 per cent summerwood in material with rings of average width (*b*).

timbers of these species as recommended by the Forest Service and adopted by the American Society for Testing Materials require that the best grades, known as Dense Southern Yellow Pine and No. 1 Structural Douglas fir, respectively, shall have on the average not less than six rings per inch, and at least one-third summerwood, or, if the rings are wider, the summerwood must constitute at least one-half of the ring, all measured as provided for in the grading rules. According to the rules for the Southern yellow pines the contrast between springwood and summerwood must be sharply defined.

Ring-porous hardwoods, as oak, ash, hickory, etc., with wide rings rank high in strength except as stated below. This variation from the relation just expressed for conifers is due to the fact that with increased width of the rings in ring-porous hardwoods the dense summerwood increases more than the porous springwood, thus making the wood heavier and stronger (Fig.

56) whereas in the conifers the springwood usually increases in width more than the summerwood as the width of the rings increases above a certain optimum for strength. Consequently, second-growth oak, hickory, ash, and elm because of their fast growth and resulting wide rings with a large percentage of summerwood are usually considered superior in strength to the narrow-ringed forest-grown timbers.

Numerous exceptions occur, especially in ash and oak, in which the summerwood may be wide but not dense, and, therefore, not strong. Consequently, there is not such a definite relation

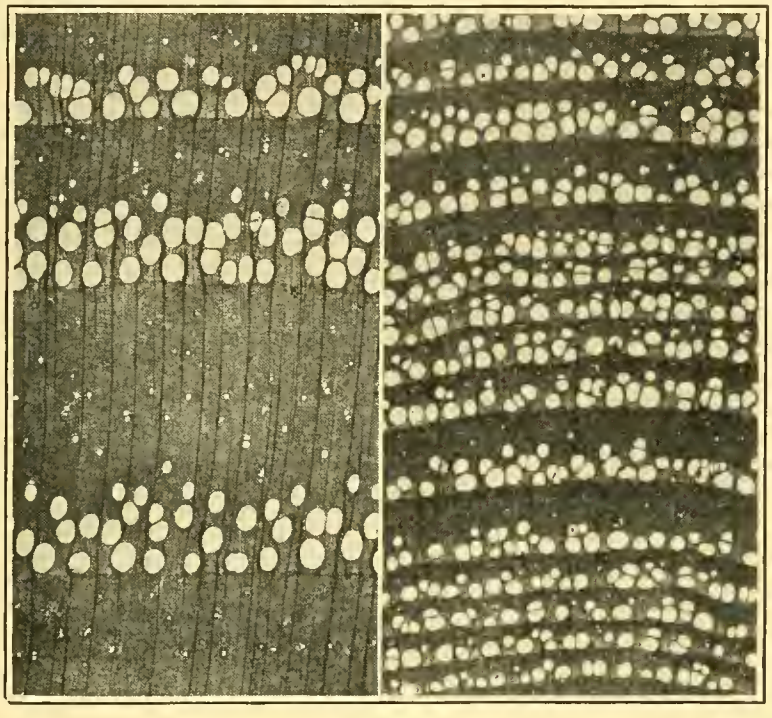


Fig. 56.—Thin cross-sections of ash magnified about 10 diameters. The wide-ringed piece at the left has a much larger proportion of dense summerwood and, therefore, better strength properties than the narrow-ringed piece at the right in which there is more springwood than summerwood. (*Courtesy, Forest Products Laboratory.*)

between strength and width of rings and per cent of summerwood in ash and oak as in southern yellow pine and Douglas fir. For example, the lower piece of ash in Fig. 57 had wide annual rings but low density summerwood, and hence was light and weak.

For the commercial grading of hickory wheel stock, rules have been adopted which require, respectively, three-fourths and two-thirds of summerwood in the highest and next highest grades of spokes and rims.

Ring-porous hardwoods with very narrow rings are apt to be weak and brash because the rings are composed mostly of springwood with large pores.

In diffuse-porous hardwoods, such as maple, birch, beech, etc., there is no definite relation between width of rings and strength except that pieces with very narrow rings often are weak and brash.

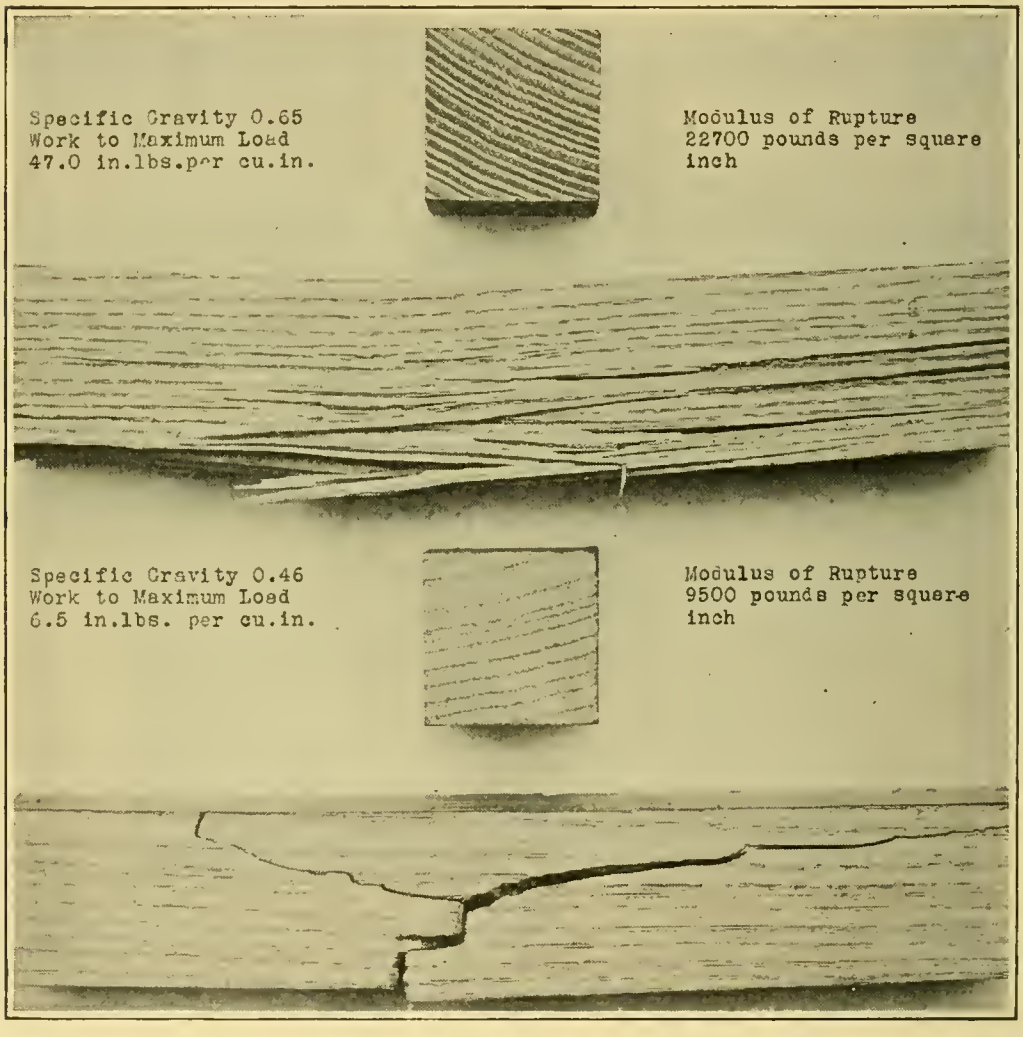


FIG. 57.—Relation of density to strength and toughness. Showing representative failures and end sections. White ash. (*Courtesy, Forest Products Laboratory.*)

For a more exact estimation of the strength of wood the specific gravity should be determined as described in Art. **17.** Stock with a specific gravity (based on oven-dry weight and oven-dry volume) not more than 10 per cent below the average for that species may be considered of good strength quality for that species if otherwise free from weakening defects as knots, cross-grain, etc.

The amount of material which will not pass these requirements for specific gravity averages about 10 per cent for each species, but in material from individual trees or limited localities it may be greater or less.

46. Differences in Species.—Differences in density alone do not account for all the differences in the strength of the various species of woods. Shock-resistance, especially, is a property which does not always closely follow the law of density, but varies with the species. For example, hickory ranks higher in shock-resistance than many other species of the same density. The conifers, as a class, rank higher in stiffness than hardwoods of the same weight. It is these exceptions and deviations from the general laws that make certain species exceptionally well adapted for certain uses.

47. Sapwood versus Heartwood.—The common impression prevails that in some species the heartwood is stronger than the sapwood, and in others, especially hickory and ash, the sapwood is stronger. Numerous tests on many species of woods show that, intrinsically, sapwood is neither stronger nor weaker than heartwood, that is, the mechanical properties of sapwood do not change appreciably when it changes to heartwood. What differences in strength may be found between sapwood pieces and heartwood pieces are due to differences in density or other causes. In mature trees very often the sapwood is weaker because the rings are narrow and the proportion of summerwood is comparatively small and, hence, the density lower in the outer portion of the tree. In young trees, on the other hand, the sapwood may be stronger because what little heartwood can be cut out of the tree must necessarily include the numerous knots found near the center, and, particularly in conifers, because of the wider rings and smaller proportion of summerwood usually found at the center.

48. Position of Growth Rings with Respect to Direction of Force.—It is a common belief that if a wooden member is loaded so that it bends in a plane approximately parallel to the annual rings it is stronger than if loaded so that it bends in a plane at right angles to the rings of growth. That is, a wagon pole with the rings running horizontally is supposed to be stronger in sidewise bending than one in which the rings are vertical.

In Forest Service tests on the cross-breaking strength of wood no consistent difference in the strength of pieces free from defects

was found between pieces tested with the rings parallel to the direction of bending, and similar pieces placed with the rings at right angles to the direction of bending.

If serious surface or honeycomb checks are present in a piece, it may be stronger if the rings are at right angles to the direction of bending, that is, horizontal in a beam, because the checks, which practically always run radially, reduce the resistance to longitudinal shear if they are at right angles to the direction of bending.

In an analysis of Forest Service tests on seasoned timbers of various species it was found that with the timbers classified as in Fig. 58 the following percentage of each class failed first in horizontal shear: Class 1, 9.5 per cent; Class 2, 6.2 per cent; Class 3, 23.5 per cent; Class 4, 18.2 per cent.[1]

Seasoned wood often splits or pulls apart more easily radially than tangentially because of the weak plane formed by uneven shrinkage where the fibers and medullary rays cross. In a limited number of tests on direct tension across the grain of seasoned specimens of six species of wood the force required to pull the wood apart in a radial plane ranged from 56 per cent in north-

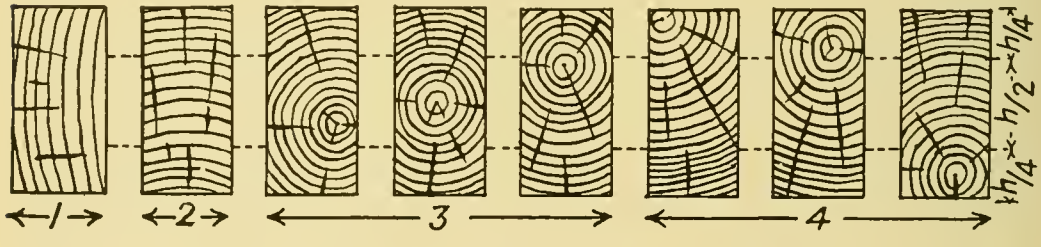


Fig. 58.—Classification of cross-sections of test specimens.
1. Pith not in cross-section. Rings vertical.
2. Pith not in cross-section. Rings horizontal.
3. Pith within center half of cross-section.
4. Pith within upper or lower quarter of cross-section.

ern red oak to 81 per cent in yellow birch of the force required to pull them apart along a tangential plane.

Wood with interlocked grain, such as the gums and sycamores, usually splits more easily tangentially than radially.

49. Portion of Tree from Which Wood Is Cut.—In some instances specimens from different parts of the same tree have been found to show considerable difference in strength. In most cases, however, the wood of the highest specific gravity has the

[1] Adapted from Cline, McGarvey and Heim, A. L., "Tests on Structural Timbers." Forest Service *Bull.* **108.**

best mechanical properties regardless of its position in the tree. Where this is not the case, the toughest or most shock-resistant material is found near the butt. Above a height of 10 or 12 feet variations of mechanical strength correspond to the variations in specific gravity. Some variations with position in cross-section or distance from the pith of the tree have been found which could not be entirely accounted for by differences in specific gravity.

The swelled butts of ash, tupelo, and cypress trees growing in the very wet swamps of the South usually contain wood lighter and weaker than the portion further up the tree trunk.

50. Locality of Growth.—In some cases the locality of growth has an influence on the strength of the timber. For example, tests show a marked difference in strength between the Rocky Mountain and Coast types of Douglas fir in favor of the Coast type.

The influence of locality is usually overestimated, however. Different stands of the same species grown in the same section of the country may show as great difference as stands grown in widely separated regions, so that as a rule locality of growth can be neglected.

51. Effect of Resin and of Turpentine.—A series of tests was made by the Forest Service a number of years ago to determine the effect of the presence of resin on the strength of wood. Longleaf pine specimens from which the resin was removed were tested in both the soaked and dry conditions and the results compared with similar tests on matched pieces containing resin. No consistent difference was found between the strength of the resinous pieces and those from which the resin was removed.

Southern yellow pine trees are abundantly tapped for turpentine, and Douglas fir trees to a minor extent. More or less prejudice exists against the so-called "bled" timber for purposes where strength is essential. Comparative tests on bled and unbled timber[1] show that (1) bled timber is as strong as unbled timber of the same weight; (2) the weight and shrinkage of wood are not affected by bleeding; and (3) practically speaking, bled trees contain neither more nor less resin than unbled trees.

52. Preservative Treatment.—The question is frequently asked whether the preservative treatment of timbers affects

[1] For details see JOHNSON, A. L., "Southern Pine—Mechanical and Physical Properties." Forest Service *Circular* **12.** This is no longer available for free distribution or purchase but may be consulted at numerous public libraries.

their strength. Tests made by the Forest Service[1] and H. . MacFarland, Engineer of Tests for the Atchison, Topeka & Santa Fe Ry.[2] show that creosote in wood does not weaken it, and zinc chloride in quantities usually injected commercially (½ pound per cubic foot) will not in itself weaken wood under static bending, although indications are that wood becomes brittle under impact. Strong solutions of zinc chloride, however, weaken wood materially, even dissolving it completely if the solution is concentrated. Treatment with a solution of zinc chloride adds moisture to the wood thereby reducing the strength of dry timber until the wood is again dried to its condition before treatment.

The preservative *process* used in treating wood may have a decidedly weakening effect on the timber. If the timber is not seasoned before treatment, it is usually steamed under pressure (to heat it through) and then rapidly dried by drawing a vacuum. The effect of the high temperature and the checking due to rapid drying are probably the chief causes of the weakening. The heat of the creosote alone, even if the timber is not steamed beforehand, may weaken the wood. Forest Service tests show that in steaming loblolly pine the limit of safety is 30 pounds pressure for 4 hours or 20 pounds for 6 hours. In general, high temperature treatments of any kind, whether in saturated steam, superheated steam, or air, make wood brittle and reduce its strength, the weakening increasing with the severity of the treatment.

53. Live versus Dead Timber.—Whether a tree is dead or alive at the time it is cut down makes in itself absolutely no difference in so far as its strength is concerned. In fact the heartwood of a living tree is entirely dead, and in the sapwood only a small proportion of the cells contain living matter. If timber which has been dead on the stump is converted into manufactured products before insects and decay attack the wood, it is of as good quality as wood cut from a living tree, unless seasoning checks have weakened or otherwise depreciated it. It might be even more desirable, for some purposes, on account of being partly seasoned.

[1] Hatt, W. Kendrick, "Experiments on the Strength of Treated Timbers." Forest Service *Circular* **39.** Sherfesse, W. F., "Wood Preservation in the United States." Forest Service *Bull.* **78.** Betts, H. S. and Newlin, J. A., "Strength Tests of Structural Timbers Treated by Commercial Wood Preserving Processes." United States Department of Agriculture *Bull.* **286.**

[2] American Railway Engineering Association *Bull.* **149.**

In view of these facts, and since insects, decay, and seasoning may also produce harmful effects on timber cut green, if not properly cared for after it is cut, the selection of wood should not be based on whether it came from live or dead timber but on whether it is sound and otherwise of proper quality.

54. Moisture Content.—As wood dries it becomes stronger in most respects, but the increase in strength does not take place until the water has passed out of the cell cavities and the cell walls begin to dry out, that is, the strength changes only below the fiber-saturation point.[1] Small clear pieces of wood dried to 12 per cent moisture, which represents a thoroughly air-dried condition, may be fully twice as strong in bending and compression along the grain as similar green pieces; and when kiln dried

TABLE XVI.—AVERAGE INCREASE IN VALUE OF MECHANICAL PROPERTIES EFFECTED BY LOWERING THE MOISTURE CONTENT 1 PER CENT, OR DECREASE BY RAISING THE MOISTURE CONTENT 1 PER CENT, WHEN AT 12 PER CENT (ABOUT)[a]

Property	Per cent
Static bending:	
Fiber stress at elastic limit	6
Modulus of rupture, or cross-breaking strength	4
Modulus of elasticity, or stiffness	2
Work to elastic limit	8
Work to maximum load or shock-resisting ability	−1
Impact bending:	
Fiber stress at elastic limit	4
Work to elastic limit	5
Height of drop of hammer causing complete failure	−3
Compression parallel to grain:	
Fiber stress at elastic limit	5
Maximum crushing strength	4
Compression perpendicular to grain:	
Fiber stress at elastic limit	6
Hardness, end grain	3
Hardness, side grain	1
Shearing strength parallel to grain	4
Tension perpendicular to grain	1

[a] From NEWLIN, J. A. and WILSON, T. R. C., "Mechanical Properties of Woods Grown in the United States." United States Department of Agriculture *Bull.* **556.**

[1] For definition of "fiber-saturation point" see Art. **19.**

to 5 per cent moisture, their strength as a beam or post may be tripled.[1] In large pieces, the increase in strength usually is not so great because of uneven drying or uneven absorption of moisture, internal stresses, and checks which may result. In structural timbers practically no increase in strength occurs in seasoning.

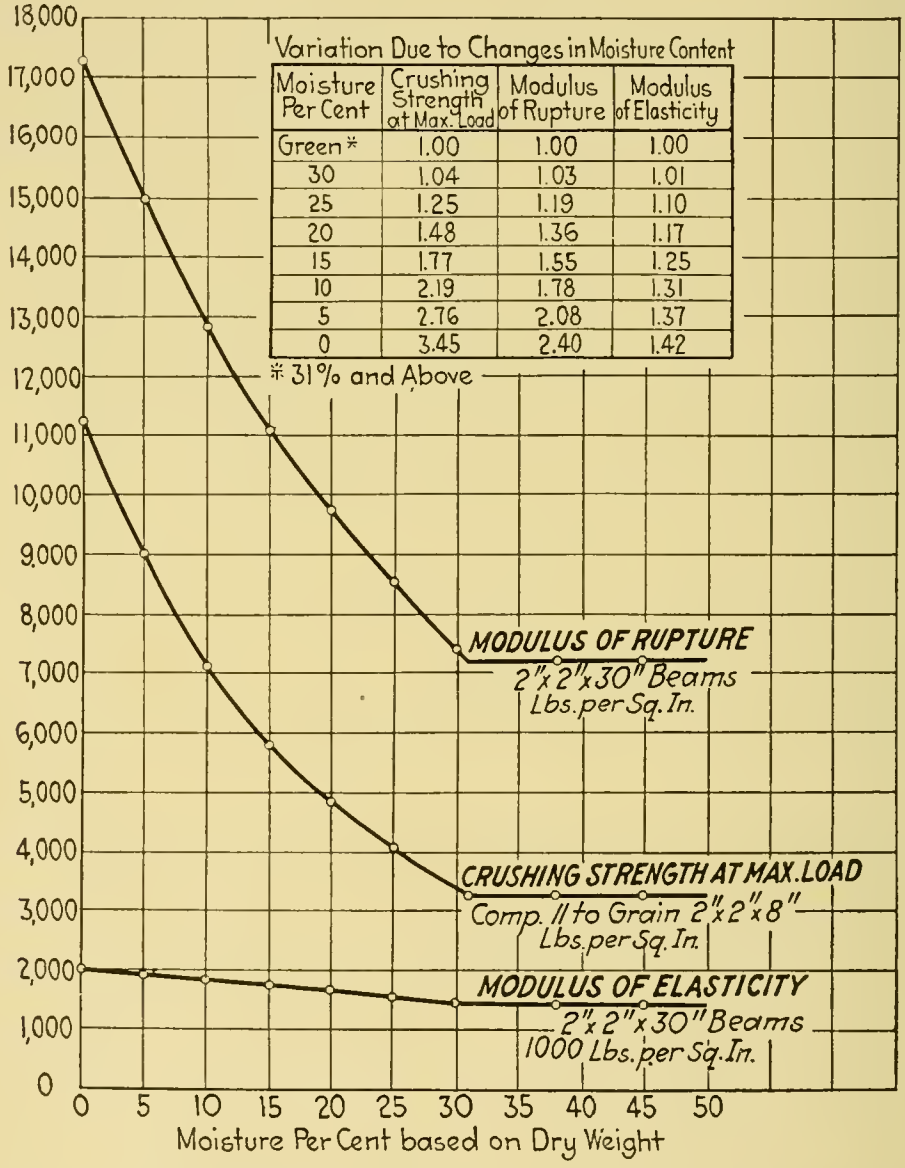


FIG. 59.—Effect of varying degrees of moisture upon the strength of small, clear specimens of western hemlock. (*From Forest Service Bull.* 115, "*Mechanical Properties of Western Hemlock.*")

The various strength properties do not increase equally with decrease in moisture content below the fiber-saturation point.

[1] TIEMANN, H. D., "Effect of Moisture on the Strength and Stiffness of Wood." Forest Service *Bull.* **70**, or "Strength of Wood as Influenced by Moisture." Forest Service *Circular* **108**, which is a summary of *Bull.* **70**.

Table XVI shows the average variation in the strength properties of small clear pieces with changes in per cent moisture at about 12 per cent. Figure 59 shows the relation of moisture content to three strength properties of western hemlock.

It will be noticed from Table XVI that while the cross-breaking strength and crushing strength parallel to the grain increase on the average 4 per cent for every 1 per cent drop in moisture at or near 12 per cent, the stiffness increases only 2 per cent.

On the other hand, the toughness, or shock-resisting ability, as indicated by both the work to maximum load in static bending and the height of drop of hammer in impact bending, actually decreases on the average as the wood becomes drier. The reason for this lack of increase in toughness during seasoning is that dry wood will not bend so far as green wood before it breaks although it will hold up a greater load. To be tough a piece must be pliable as well as strong. In some species, especially conifers, the toughness increases slightly in seasoning.

55. Method of Drying.—Considerable prejudice exists against kiln-dried wood. It is believed by many that wood artificially dried is not so strong as similar air-dried material. It is true that much wood is so badly deteriorated in dry kilns that it is inferior in strength to similar, carefully air-dried stock. Another reason for the prejudice against kiln-dried lumber is that, because it usually has a lower moisture content than air-dried material, it breaks with less bending, and the fracture usually extends more abruptly across the grain. The resulting failure makes the wood appear as if it were brash and weak. This, however, does not mean that kiln-dried wood will withstand less stress, in fact, if it is properly kiln-dried, it will take more force to break it than similar air-dried material of a higher moisture content, as is indicated in Table XVI. In other words, the prejudice is based on the appearance of the fracture and not on the load required to produce failure, or on some experiences with improperly dried material. The toughness of kiln-dried wood may be no greater and may even be less than that of similar air-dried material, but this, as is explained in Art. **54**, is caused by decrease in moisture content, and not necessarily by the heat of the kiln.

In kiln drying, wood may deteriorate in strength on account of checking, honey combing, the formation of intense internal stresses

resulting from uneven shrinkage, and chemical change in the fibers caused by too high temperatures. All but the chemical changes can be avoided to a large extent or entirely by using proper humidities in the kiln. The weakening chemical changes can be avoided by using lower temperatures. No definite rule can be laid down, however, as to how high temperatures are required for chemical changes to take place which have a weakening effect on the wood. The weakening increases with the temperature and length of time during which the wood is exposed to that temperature. The first indication of loss in strength because of too high temperatures is a decrease in shock-resisting ability, although the strength under a steady load may not be appreciably decreased; the next indication is unusual brittleness with a decrease in all strength properties, as compared with properly seasoned wood of the same dryness.

Over 200,000 tests on the effect of kiln drying on the strength of wood made by the Forest Products Laboratory in connection with the use of wood for airplanes show that if the drying temperature in the kiln does not exceed 105° F. at the beginning of the run and 135° F. at the end of the run for oak, maple, and Douglas fir and 120° F. and 145° F., respectively, for the beginning and end of the run for ash, birch, cypress, pine, and spruce, with proper gradation of temperature and humidity during the run, the wood is fully as strong as similar air-dried material of the same moisture content.[1]

56. Defects. (*a*) *Knots.*—The weakening effect of knots depends upon their size, soundness, and location, as well as on the size of the piece and the kind of stresses to which it is subjected.

In pieces subjected to bending, knots are most weakening in the middle portion of the convex side of the bent piece. Knots located on the other side are less weakening; and if located near the ends or midway between concave and convex surfaces, they are least weakening.

Unsound knots are more weakening than sound knots, and several knots close together affect the strength more than if they are scattered.

[1] For further information see Wilson, T. R. C., "The Effect of Kiln Drying on the Strength of Airplane Wood." *Rept.* 68 of the National Advisory Committee for Aeronautics, Government Printing Office, 1920.

The weakening effect of knots is brought out in the grading rules for structural timbers in Art. **43.**

(*b*) *Cross Grain.*—As already defined in Art. **12,** cross grain includes spiral grain, diagonal grain, and interlocked grain.

The slope of both spiral and diagonal grain may be expressed in a number of ways. A common way is to state in how many inches (or other units) along the length of the stick the grain deviates 1 inch (or other unit) from a line parallel to the main axis of the stick, as 1 in 20, 1 in 12, etc.

If the annual rings run diagonally across the ends of a piece so that there is no truly radial or tangential surface, the direction of the grain, as indicated by the way the piece would split either radially or tangentially with respect to the main axis of the stick, will give the true slope of spiral or diagonal grain, respectively (Fig. 60). If the sides of a piece are not parallel with the main axis, as in the case of wagon poles, the true slope of the grain can be determined only with respect to a plane parallel with the main axis and not with the faces of the piece.

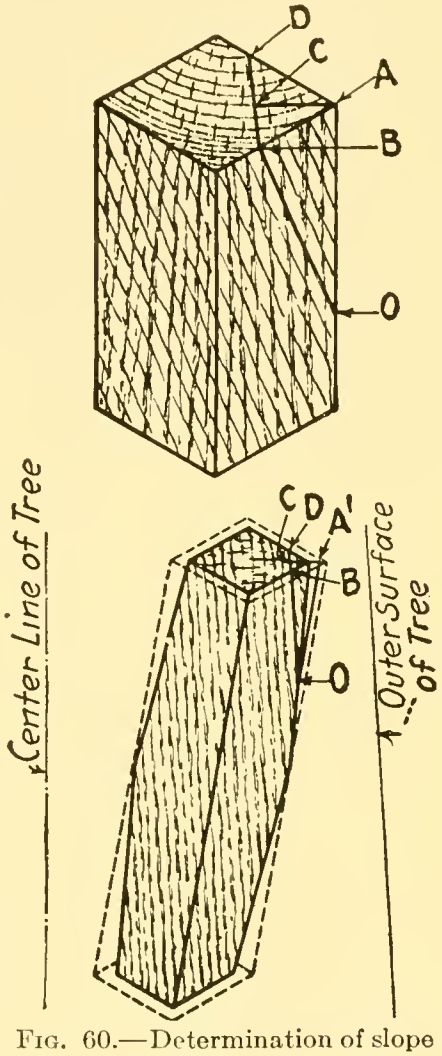


FIG. 60.—Determination of slope of grain. $\frac{AC}{AO}$ is the true slope of the grain.

Data obtained from approximately 5,800 tests on commercial white ash, Sitka spruce, and Douglas fir containing spiral and diagonal grain show that the strength does not decrease much in material with slope of grain from straight to 1 in 20. When the slope is greater than 1 in 20, the strength decreases rapidly as the slope increases. This is shown graphically for various strength properties of these species in Fig. 61.

When seasoning checks are present, spiral grain is slightly more weakening than diagonal grain of the same slope, and, since it is more difficult to detect, particular attention must be paid

to examining tangential surfaces of beams for indications of spiral grain.

Interlocked grain probably is not so weakening as spiral grain of a slope equivalent to the maximum slope in pieces with interlocked grain, especially in large pieces, although no strength tests have been made to substantiate this statement. Small pieces cut from trees with interlocked grain may have the grain slope

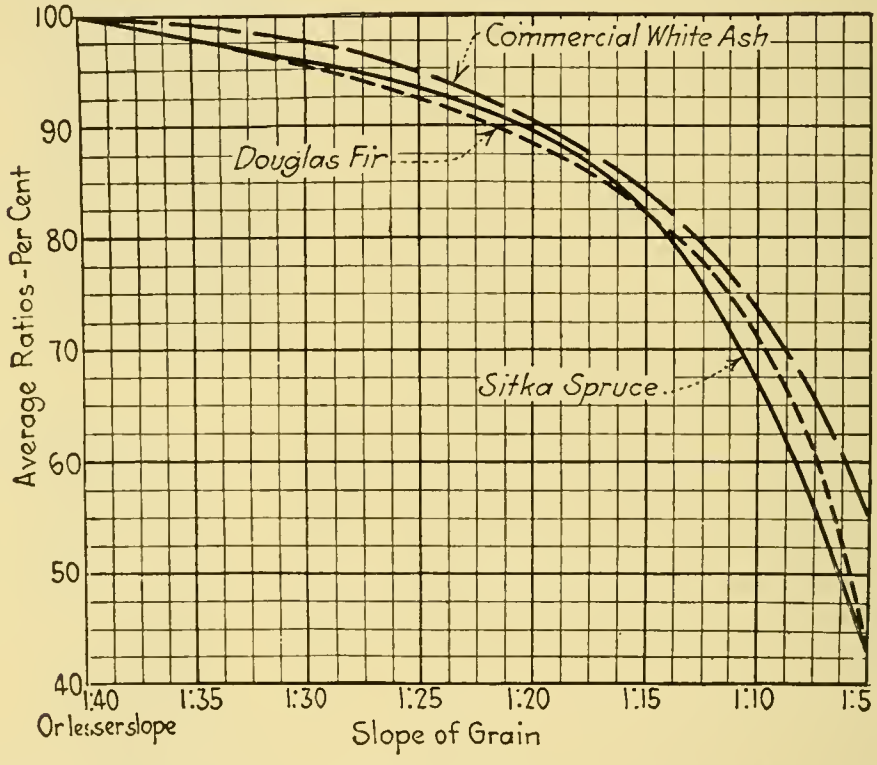


FIG. 61.—Composite curves showing the effect of spiral and diagonal grain on modulus of rupture, modulus of elasticity, and work to maximum load in static bending and maximum drop in impact bending. Third point loading, 45-inch span. Commercial white ash, Sitka spruce, Douglas fir.

almost entirely in one direction, making the effect similar to that of spiral grain.

(*c*) *Curly and Wavy Grain, and Dips in the Grain.*—Any local slope of the grain, whether it is seen on the radial or tangential face, is more or less weakening, the extent of the weakening depending upon how great the slope is and how far it extends across the piece. If the dip in the grain extends all the way across the piece, then it should be regarded as local spiral or diagonal grain of the same slope.

(*d*) *Decay, Stain, and Molds.*—The weakening effect of decay depends upon its extent and location. Very often decay extends further than is apparent on superficial inspection. The appar-

ently sound wood surrounding obviously decayed parts may contain incipient decay which is decidedly weakening, especially in shock-resisting ability. All abnormal discolorations whether lighter or darker than sound wood of any species should be regarded with suspicion as to containing decay. An exception is the blue stain found in the sapwood of many conifers and some hardwoods. This in itself is not weakening; although if the sapwood is badly stained, it indicates that the wood has been kept under moist and warm conditions for some length of time, and incipient decay may also have penetrated the wood. Red gum and some other woods normally have darker streaks in the heartwood which are not the result of decay. Molds growing on the surface of green lumber do not destroy the wood fiber to an appreciable extent and, therefore, do not affect the strength.

(*e*) *Pitch Pockets.*—These are lens-shaped openings in the grain practically flat on the side toward the pith and curved on the bark side. They contain more or less free resin and are found only in the pines, spruces, Douglas fir, and tamarack. The weakening effect of pitch pockets depends upon their size, number, location, and on the size of the piece they are in. In selecting dimension stock of the above species for purposes requiring the maximum amount of strength, greater safety will be obtained if the following rules are observed: Pitch pockets shall not exceed in length one and one-half times the least cross-sectional dimension. No pitch pockets shall be allowed in outer one-fourth of width or depth which causes a slope of grain greater than 1 in 20.

(*f*) *Shakes and Checks.*—Shakes are separations of the annual rings. They are found in green timber and may become more prominent or new ones may develop as the material seasons. Checks, including honeycomb checks, are radial splits due to uneven shrinkage in seasoning. Shakes and checks are primarily weakening in proportion to the extent to which they reduce resistance to horizontal shear. The weakening becomes greater the more nearly they approach the position of the neutral plane, that is, about midway between the compression and tension sides of a bent member.

(*g*) *Compression Failures.*—These are local wrinkles which extend across the fibers at more or less of an angle (Fig. 62). They are due to the wood having been compressed parallel with the fibers nearly to or beyond the maximum load. This may occur

in severe bending of the tree trunk by the wind, or by felling trees or dropping logs over other logs, boulders, etc., or by stressing pieces well beyond the elastic limit when in use.

Compression failures are difficult to detect but very weakening.

(*h*) *Heart or Pith.*—The wood immediately surrounding the structural center of a tree trunk contains numerous knots, often small checks extending out from the pith, and occasionally shakes. At the center in conifers the wood fiber itself is relatively weak as a rule. For this reason the center should not be included in small dimension stock subjected to heavy loads.

(*i*) *Worm Holes.*—Occasional worm holes in wood do not seriously weaken it, but pieces which are badly perforated by

FIG. 62.—Compression failure in Douglas fir. (*Courtesy, Forest Products Laboratory.*)

insects should not be used where strength is essential. In lumber or manufactured parts which have been in storage for some time the worm holes may be much more serious in the interior than is indicated on the surface. This is true, especially of the sapwood of ash, oak, hickory, elm, and some other hardwoods which are attacked by the powder-post beetle.[1] Wood which has been attacked by "white ants" may have practically the entire interior eaten away leaving only a shell.

(*j*) *Bird Pecks and Mineral Streaks.*—In maple, hickory, and some other woods bird pecks usually cause a dark discoloration of the wood above and below the peck. These dark streaks are often infiltrated with mineral deposits making them very hard.

[1] HOPKINS, A. D. and SNYDER, T. E., "Powder-post Damage by Lyctus Beetles to Seasoned Hardwood." *Farmers' Bull.* **778.**

No test data on the weakening affect of bird pecks are available. Occasional pecks several inches apart undoubtedly have no appreciable weakening effect, except in small pieces, but several in a row (as often occurs), especially if in the middle portion of the surfaces which bend most, would have a decidedly weakening effect, particularly in such articles as buggy spokes, shafts, and handles.

57. Factors Affecting the Nail-holding Power of Wood.— The strength of a nailed joint depends upon the kind, thickness, and condition of the wood, and on the kind and number of nails used. In general, the greater the dry weight, or specific gravity, of the wood, the more firmly it will hold a nail. Table XVII gives the nail-holding power of certain species, and Fig. 63 shows graphically the relation between density and nail-holding power of wood. This table shows that nails driven into the end grain are more easily pulled than those driven into the side grain in all species except those of exceptionally high density, and that it makes no consistent difference, taking all species into consideration, whether the nail is driven into the radial or into the tangential surface.

When a nail is driven into a dense piece of wood, it produces a much greater splitting force than when the same nail is driven into a soft piece of wood; on the other hand, a dense piece of wood has greater resistance to splitting than a light piece of wood. These two factors tend to counterbalance each other but do not do so entirely. The dense species, as a rule, will split somewhat more than the lighter species with the same nailing. For example, a piece of dense yellow pine will split more easily in nailing than a piece of white pine even when the same kind of a nail is used; and oak and maple flooring must have the tongue bored for nail holes while yellow pine and fir flooring can be nailed satisfactorily without boring.

Because green wood is much softer than dry wood, nails can be driven in and withdrawn from it much more readily than from dry wood. A nail driven into green wood which is later dried can be removed more easily than one driven into dry wood. The underlying reason for this is that wood shrinks considerably across the grain but little along the grain. In driving a nail the fibers on the two lateral sides are crushed sideways, while those on the two end grain sides are bent downward as shown in Fig. 64. As the wood dries it shrinks and closes in on the nail

from the two lateral sides, but on the other two sides the transverse shrinkage of the fibers turned down is greater than the longitudinal shrinkage of the wood in general, and so the pressure on the nail is relieved on these sides, which, in fact, are the sides with which the nail was more firmly held in the first place.

TABLE XVII.—PULL REQUIRED TO WITHDRAW 7-PENNY CEMENT COATED NAILS DRIVEN 1¼ INCHES DEEP INTO DRY WOOD

Species	Moisture	Specific gravity	Pull in pounds		
			End surface	Radial surface	Tangential surface
Hardwoods					
Ash, white	8.9	.640	347	410	407
Aspen, largetooth	6.5	.412	141	182	186
Basswood	6.5	.412	124	179	175
Beech	8.4	.669	322	446	414
Birch, yellow	8.6	.661	298	426	406
Cottonwood	6.8	.343	129	170	177
Black	5.9	.368	110	175	176
Elm, white	8.2	.537	212	310	305
Gum, blue (Eucalyptus)	4.8	.796	368	381	367
Red (heartwood)	6.0	.488	179	238	243
Red (sapwood)	8.1	.433	189	237	220
Hornbeam	6.5	.718	412	462	432
Locust, black	4.1	.708	364	415	311
Honey	6.5	.759	388	458	404
Maple, sugar	9.3	.643	350	445	406
Silver	6.8	.506	252	300	304
Oak, cow	4.3	.756	277	392	323
Post	7.3	.732	351	375	345
Red	7.6	.660	297	349	333
White	7.3	.696	268	256	289
Orange, osage	6.6	.838	478	390	371
Sycamore	7.0	.552	243	332	314
Yellow poplar	7.3	.419	146	191	201
Conifers					
Cedar, white	9.3	.315	93	138	144
Fir, white	7.6	.437	101	157	183
Hemlock, Wisconsin	11.6	.400	115	212	213
Tennessee	8.6	.501	139	210	236
Pine, jack	7.6	.429	145	205	245
Loblolly	7.7	.516	142	219	268
Longleaf	8.2	.599	196	291	313
Norway	7.4	.507	149	246	254
Western yellow	7.2	.433	96	183	196
White	7.7	.391	122	198	203
Spruce, Engelmann	9.4	.359	122	159	166
Red	10.7	.413	133	206	199
White	7.6	.396	131	188	196

A nail driven into a dry piece of wood which afterward is allowed to become soaked and then redried will act as does a nail driven into green lumber which is then dried.

Tests made in the box-testing division of the Forest Products Laboratory show that, at least in the ordinary sizes, barbed nails do not hold so well in boxes and cement coated nails hold better than smooth, uncoated nails.

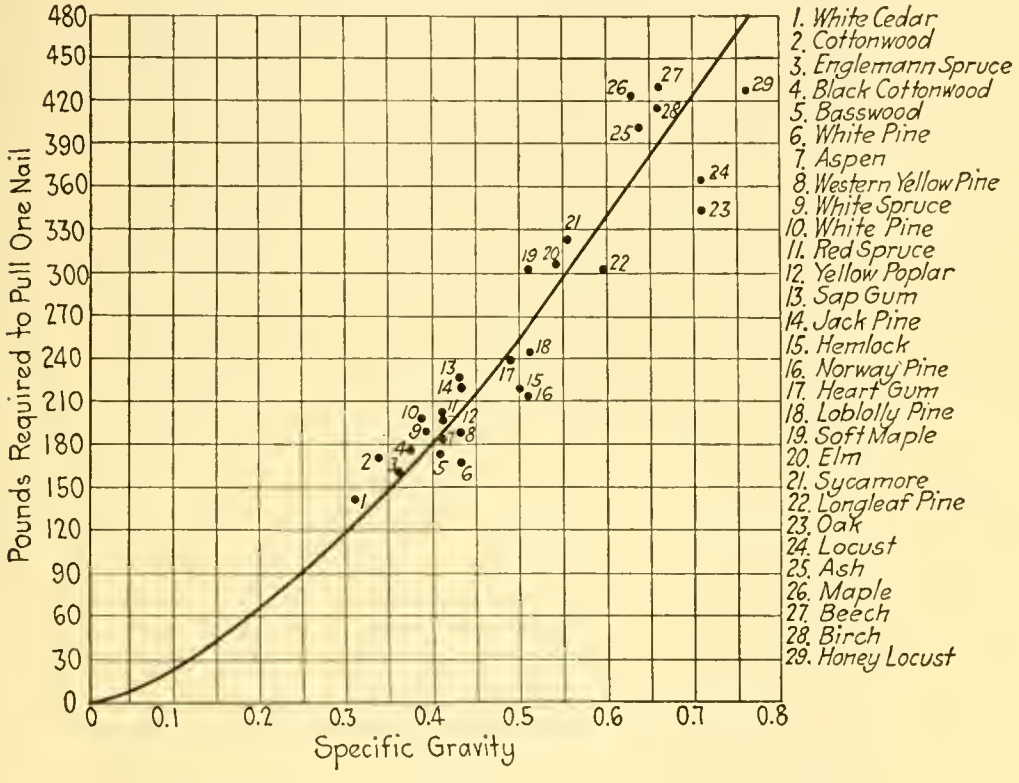


FIG. 63.—Chart showing relation of density to nail-holding power (side grain.)

If the board which is next to the nail head is thin, if the nail head is small or easily stripped, or if the nail is over-driven, the joint is not so strong as if proper materials and methods are used.

The holding power of a nail varies approximately as its volume. To reduce splitting to a minimum, as slender a nail as can be driven satisfactorily should be used; if the nail is too slender, however, it will not drive well. The longer a nail is, the greater must be its diameter in order to insure that it will drive.

The Forest Products Laboratory recommends that in nailing packing boxes when the slender, or "box," nail is used, and when the lumber is of medium hardness, the "penny" of the nail should be no greater than the thickness in eighths of an inch of

the wood which holds the point of the nail. For the softer woods, nails may be one "penny" larger and sometimes two "pennies." For the harder woods, nails one "penny" smaller should be used.

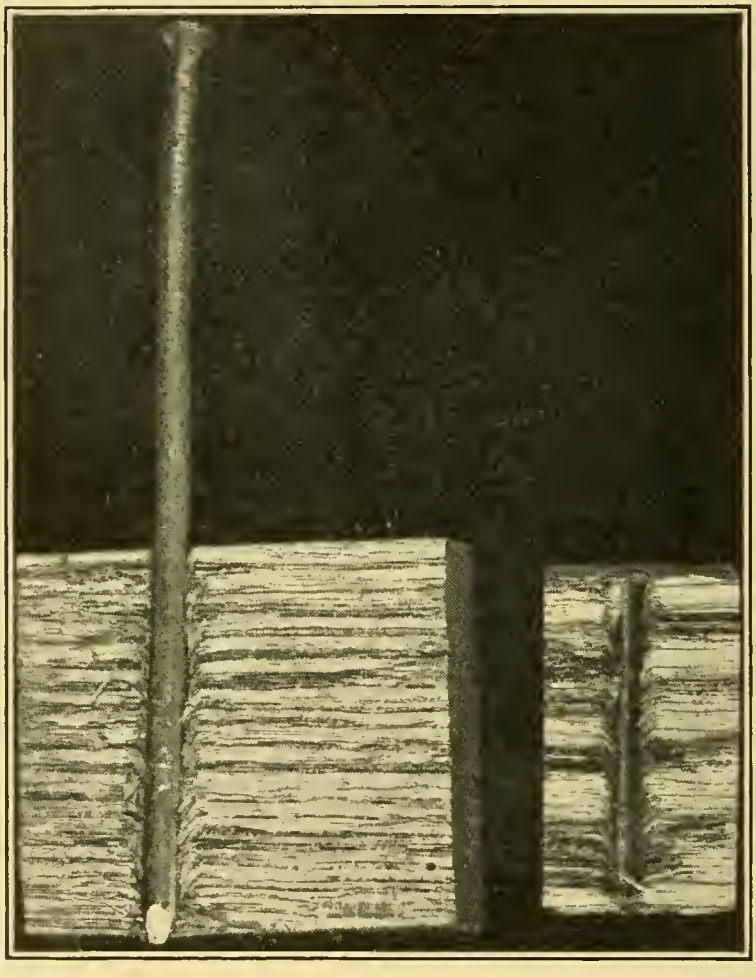


FIG. 64.—Displacement of red oak fibers by nails. (*Courtesy, Forest Products Laboratory.*)

For six "penny" or smaller nails held in the side grain, the spacing between nails should be 2 inches, and for the same nails in the end grain the spacing should be 1¾ inches. For larger nails the spacing should increase ¼ inch for each "penny." With this nailing the strength of the nailed joints will still be somewhat less than the strength of the box in other respects.

CHAPTER VI

CHEMICAL PROPERTIES OF WOOD AND THEIR PRACTICAL APPLICATION

The chemical properties of wood are those which are manifested by any change, or resistance to change, in the composition of the wood substance when associated with other materials or when subjected to various forms of energy such as heat, electricity, light, or pressure. Wood is comparatively inert in some respects, as in its resistance to attack by many dilute acids, salt water, or fumes; on the other hand, wood is readily oxidized (burned), dissolved, or converted into some other products under proper conditions.

The chemical properties of wood which are of chief interest to the average consumer of lumber are its combustibility and its fuel value. Those properties which are made use of in the manufacture of other materials, such as paper, alcohol, or artificial silk, usually interest the average user of lumber only in so far as the manufacture of such products from waste material increases the revenue which may be derived from the forest, thereby assisting in keeping down the price of lumber.

To the lumberman and to the manufacturer of wooden products, however, the chemical conversion of wood should be an interesting field of investigation. With the rising price of stumpage, increased operating costs, and the competition of cement, brick, stone, and steel (which checks corresponding increase in the selling prices of lumber) any method of obtaining additional income from the forest or from waste at the factory may mean the difference between success and failure.

It is estimated that 36 million cords of waste wood are produced annually at the sawmills in the United States. About one-half of this is burned under the boilers and serves a purpose, but most of the other half is destroyed in refuse burners or otherwise. Much of this material is of such small size that it is not fit for further direct manufacture, but for chemical means of conversion this small size is no detriment, except that it may add a little

to the cost of handling. However, even burning waste in a refuse burner costs money. In addition to the sawmill waste, it is estimated that about one-fourth of the wood growing in the forest is left after logging in the form of long tops, high stumps, defective logs, large limbs, and other material which will not furnish lumber. The possibility of using this material is not an idle fancy; already the more progressive operators are using this waste in wood distillation, in the manufacture of pulp, and in other processes involving chemical conversion.

58. Chemical Composition of Wood.—The chief solid constituent of wood, and in fact of most plant tissues, is cellulose. Cellulose consists of carbon, hydrogen, and oxygen, and is represented chemically by the formula $(C_6H_{10}O_5)_n$. The proportionate amount of each of these elements is the same as in starch, but cellulose differs from starch in that it will not form a colloidal solution in hot water, it is less easily hydrolized, and is not digestible by man, although some animals can digest it in part.

Cellulose occurs in almost pure form in cotton and flax fibers, whereas in wood other materials are associated with it. About 60 per cent[1] of the dry weight of wood is cellulose, but commercial processes rarely yield over 45 per cent.

Cellulose is a colorless, hygroscopic, combustible material insoluble in ordinary solvents such as water, alcohol, ether, and benzine, but completely soluble in hydrochloric acid (40 per cent and stronger), concentrated sulphuric acid, strong zinc chloride solution, cuprammonia, and concentrated ferric chloride solutions. Nitric and chromic acids oxidize cellulose, the compounds formed being soluble in these acids.

Combined with cellulose,[2] and comprising about 20 to 25 per cent[3] of wood substance, is a complex material called lignin, which also is composed of carbon, hydrogen, and oxygen, but in different proportions, being relatively richer in carbon and poorer in oxygen than cellulose. The chemical formula for lignin is variously expressed as $C_{36}H_{44}O_{14}$, $C_{36}H_{40}O_{12}$, and $C_{40}H_{42}O_{11}$,

[1] Schorger, Dr. A. W., "The Chemistry of Wood." *J. Ind. Eng. Chem.*, vol. IX, no. 6, June, 1917.

[2] It is not definitely known whether the combination is merely physical or chemical.

[3] Schwalbe, C. G. and Becker, E., *Zeitschrift Angewande Chemie*, vol. 32, pp. 229–231. (Abstract in *J. Soc. Chem. Ind.*, vol. 38, no. 17, p. 624, Sept. 15, 1919.)

although some investigators consider it a mixture of several compounds. In 100 parts of dry wood and cellulose the following proportions by weight are found:

	Wood (approximately)	Cellulose
Carbon	49	44.4
Hydrogen	6	6.2
Oxygen	44	49.4

It is the lignin in wood which gives it its distinctive characteristics, making it different from pure cellulose fibers, bark, and other tissues.

Lignin differs from cellulose in being soluble to a greater or lesser extent in dilute acids and alkalis, in being more readily attacked by oxidizing agencies, and in not being soluble in cuprammonia.

In addition to cellulose and lignin a few other substances enter into the formation of woody tissues though in relatively smaller amounts. Hemicelluloses (which are more easily hydrolized than true celluloses) are found in some woods in considerable quantities. Pectic compounds form the principal constituent of the cementing material which binds the cells together. They are more easily soluble in certain chemicals than the cell walls proper, and hence, in digesting wood for paper pulp, it is the pectic layer and the lignin in the cell walls which are dissolved, leaving the isolated cellulose fibers.

Infiltrated in the cell walls of wood there may be mineral matter of various kinds (principally silica, calcium oxalate, and calcium carbonate), dyes, tannins, resins, oils, etc. These are also found in some of the cell cavities, and in addition there may be sugars, starches, gums, nitrogenous compounds, and other substances. It usually is in the amount of these associated materials that one wood differs chemically from another, the composition of the cell walls proper being very much alike, although slight differences do occur.

59. Combustibility of Wood.—When dry wood is heated slightly above the boiling point of water (212° F.), gradual

decomposition sets in.[1] If this temperature is continued for a long time, its effect on the wood will be indicated by brittleness and darkening in color. At a temperature of about 320° F. the decomposition is more rapid and the wood assumes a charred appearance. At 480° F. a brownish charcoal is produced and, above 575° F. the charcoal becomes black and metallic.

The length of time at which comparatively low temperatures must be applied to wood before ignition takes place in the pres-

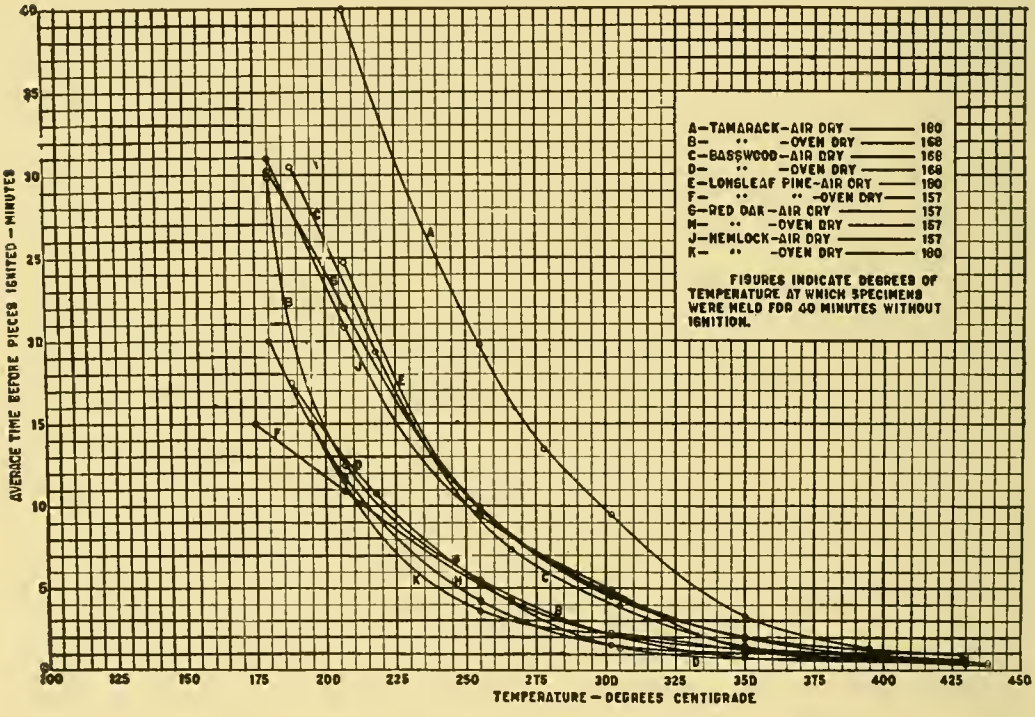

AVERAGE TIME BEFORE PIECES IGNITED — MINUTES
TEMPERATURE — DEGREES CENTIGRADE
A—TAMARACK—AIR DRY 180
B— " —OVEN DRY 168
C—BASSWOOD—AIR DRY 168
D— " —OVEN DRY 168
E—LONGLEAF PINE—AIR DRY 190
F— " " —OVEN DRY 157
G—RED OAK—AIR DRY 157
H— " —OVEN DRY 157
J—HEMLOCK—AIR DRY 157
K— " —OVEN DRY 190
FIGURES INDICATE DEGREES OF TEMPERATURE AT WHICH SPECIMENS WERE HELD FOR 40 MINUTES WITHOUT IGNITION.

FIG. 65.—Time required for different woods to ignite when subjected to various degrees of heat, a small flame being placed over the wood to ignite combustible gases. From Proceedings of the 1915 meeting of the National Fire Protection Association.

ence of a spark or pilot flame varies somewhat with the species but more with the degree of dryness of the wood. This is illustrated by the curves in Fig. 65, and so also is the fact that as the temperature increases all woods ignite more rapidly. At 400° C. or 752° F. all woods ignite very quickly. Since the temperature of a burning building is considerably above 1,500° F., it is evident that the kind of wood of which it is constructed has very little to do with its inflammability. However, since

[1] SPAULDING (Studies in the Lignin and Cellulose of Wood; Missouri Botanical Garden *Ann. Rept.*, 1906) found that if wood is heated to 212° F. for 15 to 40 hours, a slight change takes place in the composition of the wood elements.

light woods are consumed more quickly in a fire than heavy woods, a soft pine structure will succumb to the flames more quickly than one of the same dimensions built of oak.

Wood will ignite spontaneously at temperatures slightly over 525° F. Under proper conditions sound hemlock has been ignited at air temperatures as low as 428° F. and decayed hemlock at 406° F. without the presence of a pilot flame to ignite the evolved gases.[1]

The fact that wood does ignite at comparatively low temperatures is important. Many fires have originated from woodwork being in contact with heating pipes. The wood first chars very slowly and then ignites.

Fresh charcoal made in closed retorts is even subject to spontaneous combustion at ordinary temperatures on exposure to air. Numerous instances are on record of charcoal which ignited spontaneously in freight cars or while in storage without the application of heat from the exterior.

60. Fuel Value of Wood.[2]—Although coal, natural gas, and petroleum products are being used for fuel more and more, an enormous amount of firewood is still consumed annually in this country. Various estimates give this amount as 90,000,000 to more than 110,000,000 cords. It is probably safe to say that as great a volume of wood is used for firewood as for all other purposes combined. A discussion of the heating value of wood will, therefore, be of interest.

Equal weights of dry nonresinous woods give off practically the same amount of heat in burning; that is, a ton of dry cottonwood will give off as much heat in burning as a ton of white oak. Highly resinous woods, like some pieces of pine and Douglas fir, have an appreciably greater heating value per ton, because a pound of resin gives off about twice as much heat during combustion as a pound of wood.

When wood is bought by the cord, it should be remembered that different species vary greatly in weight and, therefore, in heating value. For example, a cord of hickory has considerably more fuel value than a cord of soft maple.

[1] Hill, H. B. and Comey, A. M., "On the Behavior of Sound and Decayed Wood at High Temperatures." *Proc. Am. Acad. Arts Sci.*, vol. XXII, p. 482, 1886.

[2] See "The Use of Wood for Fuel." United States Department of Agriculture *Bull.* **753.**

The amount of moisture in firewood influences not only the vigor with which it burns but also the amount of heat actually given off to the surroundings. The heat required to drive out the moisture and convert it into steam is considerable. Firewood should, therefore, be well seasoned before it is used.

Other factors, however, should also be taken into consideration in selecting firewood, such as price, the rapidity and completeness of combustion, quickness of heating and uniformity of heating, depending upon the particular results desired. As a rule the conifers burn more readily than the hardwoods, and the lighter woods burn more readily than the heavier ones.

In comparing the heating values of coal and wood, one pound of good coal is considered as the equivalent of two pounds of seasoned wood. Allowing 80 solid cubic feet of wood to an average cord of wood, and assuming the sticks to be well seasoned, a cord of hickory or other heavy wood is equivalent in heat value to one ton of coal. For the lighter woods, such as cedar, white pine, poplar, and spruce, two cords are equivalent to 1 ton of coal.

In Table XVIII wood is compared with other fuels. It will be seen that wood has a much larger proportion of oxygen than coal. This oxygen already is combined with some of the carbon and hydrogen and, hence, the heating units given off in combustion are that much reduced. This fact, together with the comparatively large percentage of moisture in wood, accounts for its lower heating value per pound.

TABLE XVIII.—COMPARISON OF COMPOSITION AND HEATING POWER OF VARIOUS FUELS

Fuel	Per cent							Heating units B.t.u. per pound[a]
	Water	Carbon	Hydrogen	Oxygen	Nitrogen	Ash	Sulphur	
Wood	20.0	39.0	4.4	35.6	...	1.0	...	8,000[b]
Bituminous coal	0.6	80.5	4.9	5.4	2.1	5.8	0.7	13,000
Anthracite coal	3.2	82.4	2.5	2.7	0.8	7.8	0.6	13,000
Charcoal	....	97.0	...	....	...	3.0	...	16,000

[a] From Bureau of Standards *Circular* **70**, "Materials of the Household."

[b] Probably meant for wood with considerably less than 20 per cent moisture.

61. Producer Gas from Wood.—Wood can be utilized for making gas to be used in internal combustion engines or for

heating purposes, similar to the way in which coal gas or natural gas is used. The gas which is known as "producer gas" is made by the partial combustion of the wood in air mixed with steam. Although this process is developed to a greater extent in France and Sweden than in the United States, it has possibilities in parts of this country where other fuel is difficult to obtain and wood waste is abundant.

62. Paper Making.—Approximately 90 per cent of all the paper manufactured in the United States is made of wood. In round numbers 5,000,000 cords of pulpwood are used annually by the pulp-making industries of the United States. Spruce, hemlock, balsam fir, yellow pine, and aspen (popple) are the principal woods used. A large variety of other softwoods and hardwoods are used in smaller quantities. Slab wood and other mill waste furnish about 200,000 cords of pulpwood annually, although this varies considerably from year to year. The chief drawback against the wider use of mill waste for paper is the cost of handling and barking small pieces.

Wood is used in preference to other paper-making materials because the raw material can be obtained in large quantities and at a reasonable price; it is easily transported and handled, especially by machinery; it is comparatively free from dirt; and because of its compactness large quantities can be stored or worked up at one time.

In the making of paper the bark is removed from the wood and the fibers are separated either by mechanical means, that is, grinding on a grindstone (strictly speaking this is not a chemical process), in which case the product is known as "mechanical" or "groundwood pulp," or by cooking with chemicals in which case the product is known as "chemical pulp."

Groundwood pulp is used principally in the manufacture of cheap papers. Newspapers consist of from 70 to 85 per cent of groundwood and from 15 to 30 per cent of sulphite pulp. Usually groundwood pulp is not bleached (sometimes it is partly bleached), and it has a yellowish tinge which is partly neutralized by the addition of a certain kind of bluing. Spruce ranks first by far in the production of groundwood, but hemlock and balsam fir are also used in considerable quantities.

Chemical pulp is made by three different processes, producing what are known as "sulphite" pulp, "soda" pulp, and "sulphate" pulp. For all these processes the wood is chipped into pieces

about ¾ inch long. These chips are cooked in a digester for from 2 to 30 hours with the necessary chemicals, namely, bisulphite of calcium and magnesium with a small amount of sulphurous acid, or caustic soda, or sodium sulphide mixed with caustic soda, depending respectively upon which of the processes referred to above is used.

Fig. 66.—Pulpwood in boom, Glen Falls, New York. Each year this country requires for pulp and paper the equivalent of all the usable wood on 470 square miles well stocked with spruce. Since a large part of the land from which pulpwood is cut is not well stocked, a considerably larger area must be cut over each year to supply the country's needs. (*Courtesy, U. S. Forest Service.*)

For sulphite pulp, spruce is the principal wood used, although hemlock, balsam fir, and pine are also used to a considerable extent. Fully half of all the woods used for paper making are converted into pulp by the sulphite process. Unbleached sulphite pulp is used extensively for newsprint, wrapping paper, and boxboard. Bleached sulphite pulp is used largely for book papers and writing paper. Tissue paper and paper used for wrapping fruit are also made mostly of sulphite pulp, either bleached or unbleached.

For soda pulp, aspen furnishes over half of the wood used. Soda pulp is used principally for high-grade book paper, ledger

paper, and, mixed with rag stock, it is made into writing paper. It makes a softer and more opaque paper than the sulphite pulp which usually produces a "tinny rattle" when handled. Papers as a rule are not made of one kind of pulp; a mixture is usually required to obtain the desired stock.

For the sulphate process, which consumes only a small proportion of the total amount of pulpwood cut, yellow pine, jack pine, hemlock, and tamarack are the principal woods used. This process is especially suitable for resinous woods. The pulp is rarely bleached; and if mill waste is used, the bark is not always removed. For this reason sulphate pulp is seldom used for anything but wrapping paper, for which it is well suited on account of its strength. This process derives its name from the sodium sulphate which is used to make up for the sodium salts lost in the cooking process. It is the sodium sulphide which is the active agent.

The pulp and paper industry has an economic relation to the lumber industry in that it produces a market for the small, crooked, defective, and inferior kinds of timber and mill waste which otherwise would be practically worthless.

63. Wood Distillation.[1]—The process of making charcoal by burning wood in a pit or in a pile covered with earth has long been associated with the smelting of iron for which charcoal is largely used. The charcoal pit has been replaced to a large extent by the retort or oven in which the wood is heated from the outside without access of air. This is known as destructive distillation. In this way a number of other valuable products are obtained. The gases given off are passed through a condenser, and a watery distillate known as "pyroligneous acid" and some tar which settles out are produced. This liquor contains from 3 to 4 per cent of wood alcohol, 10 to 12 per cent of acetic acid, 5 to 6 per cent of dissolved tar, and the rest is water. In redistillation the dissolved tar is separated from the acetic acid and alcohol. The acid is then neutralized with lime, producing gray acetate of lime, and the alcohol is refined. This process is shown diagrammatically in Fig. 67.

In the destructive distillation of hardwood, birch, beech, maple, oak, and ironwood have been found the most profitable. Timber down to 3 or 4 inches in diameter and large sawmill

[1] For further information see HAWLEY, DR. L. F., "Wood Distillation." The Chemical Catalogue Co., New York, 1923.

slabs can be utilized in this industry, thus affording a market in certain localities for material otherwise of practically no value.

Of the charcoal produced in retorts and ovens about 75 per cent is used in blast furnaces; 20 per cent is used for domestic purposes; and the other 5 per cent finds various uses, one of which is in black powder.

About 75 per cent of the acetate of lime is reconverted into acetic acid, and 25 per cent into acetone. The acetic acid is used largely in the dyeing industry. Some is used for medicinal purposes, and some in laboratories. The acetone is used in the manufacture of smokeless powder, chloroform, iodoform, sulphinol, moving-picture films, and as a solvent.

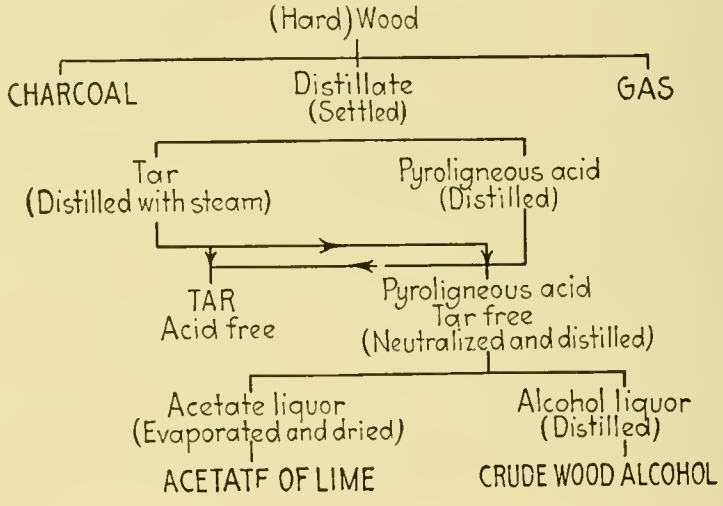


FIG. 67.—Products derived from the destructive distillation of hardwoods.

Wood alcohol is used as a denaturant of grain alcohol, and in the manufacture of formaldehyde, aniline dyes, medicines, explosives, moving-picture films, etc. Formerly a large amount was used in the manufacture of varnishes, but now little is used in this way. It is poisonous when taken internally, and the fumes are also injurious, producing blindness and even death.

The wood tar when redistilled yields wood tar creosote and pitch. The former is used in the manufacture of stains and flotation oils, and the latter for insulating purposes.

In the destructive distillation of softwoods the most important commercial products obtained are wood turpentine, pine oils, tar oils, and charcoal. The pyroligneous acid obtained from conifers does not contain sufficient alcohol and acetic acid to warrant its redistillation. It is sold as a wood stain and as a

fly repellant for use in stables and barns. The "wood turpentine" obtained by this method is inferior to the "gum turpentine" obtained by tapping the trees and is used for the cheaper paints and varnishes. The tar oils are used as disinfectants, paint driers, and flotation oils. The tar is used for treating ropes and cables employed about ships.

About 200,000 cords of wood are used each year in the destructive distillation of softwoods in this country.

Highly resinous yellow pine is distilled by means of steam at a temperature which will not disintegrate the wood. For this process the wood is chipped. The chief products are wood turpentine and pine oil. Rosin is extracted from the chips by means of petroleum oil solvents. The extracted chips are usually used as fuel.

64. Leaching of Wood.—Woods which have lain in water for a long time are reputed to shrink, swell, and warp less in use than those which have received ordinary treatment. The Japanese have a custom of leaving their high-grade lumber in water for several years before using it. Apparently some leaching takes place which improves the quality of the lumber. Schorger,[1] in making analysis of finely divided samples of seven American woods, found that from 0.9 to 12.8 per cent of the wood, based on the oven-dry weight, may be extracted with cold water, and up to 15.3 per cent with hot water. Schorger further states that the chief materials extracted by water are tannins, bitter principles, and carbohydrates. Possibly the removal of some of these materials from the wood has an effect on its physical properties, but obviously it takes a long time for timber of commercial sizes to be leached to an appreciable extent.

65. Extracts from Wood. (*a*) *Tannin.*—Chestnut is the only native wood which furnishes tannin in commercial quantities. Tannin is also derived from the barks of the eastern and western hemlocks, chestnut oak, California tanbark oak, white oak, and black oak, and from the leaves and young stems of sumach, although the last three species furnish comparatively little tanning material. The bark of chestnut contains only from 2 to 3 per cent tannin, which is not sufficient to make its separate collection profitable, but it is taken with the wood which contains from 7 to 12 per cent based on the air-dry weight.

[1] SCHORGER, DR. A. W., "The Chemistry of Wood." *J. Ind. Eng. Chem.*, June, 1917.

Chestnut wood is by far the most important native tanning material. In making the extract the wood is first "hogged" or chipped and then put into large vats where it is leached with hot water. The resulting solution is concentrated by evaporation before it is shipped. This is again diluted at the tannery before it is used.

A South American wood known as "quebracho" and the mangrove of tropical America are also important sources of tannin.

Tanbark is used directly in the vats with the leather to be tanned, or an extract is made from it, or both tanbark and tannin extract are used. In fact a mixture of tannins from different sources often gives better results in tanning leather than the use of one kind. Tannin derived from trees is used mostly in tanning heavier hides to be used for soles, harnesses, beltings, etc. The lighter skins, as calf, goat, and sheep, are usually tanned with chromic acid.

(*b*) *Dyes.*—Osage orange is the only native wood that furnishes a dye in commercial quantities. That which grows in the South is said to be richer in dye than that which grows in the North. The dye is yellow to golden brown in color and is used in dyeing leather as well as textiles.

The inner bark of our native black oak, or yellow oak (*Quercus velutina*) also furnishes a yellow dye. The bark of butternut and the hulls of black walnut, also alder, red gum, sumach, and dogwood all had important uses as dye materials among the early settlers and Indians, but have been replaced by other coloring materials, especially the coal tar dyes.

(*c*) *Rosin.*—In the steam distillation of resinous wood only the turpentine and pine oils are obtained. The non-volatile rosin is left in the wood as already stated in Art. **63.** This rosin may be extracted by means of gasoline, benzine, or other solvent, thus obtaining another product from the wood. The solution obtained is evaporated, leaving the rosin as a residue. The solvent is recovered in part at least.

Although this form of rosin is not of so high a quality as that obtained by turpentine orcharding, it usually finds a ready market in the manufacture of linoleum, soaps, printing ink, and other materials.

Highly resinous pieces of pine known as "lightwood" are most profitable for extraction. Such wood is found only in the heartwood and may contain from 10 to 30 per cent resin. (Resin is a

mixture of turpentine, pine oil, and rosin.) Ordinary pine heartwood contains from 2 to 10 per cent resin. The sapwood contains a less amount, varying from 1 to 4 per cent and is not profitable for extraction. The use of the extracted chips as a raw material for paper pulp promises to be a source of additional profit from this industry.

66. The Manufacture of Ethyl (Grain) Alcohol from Wood.—Wood is composed mostly of the same elements as sugar, namely, carbon, hydrogen, and oxygen, only in different proportions. By treating the finely divided wood with dilute acids it is converted partly into sugars some of which are fermentable by yeast under certain conditions, producing ethyl alcohol identical with that derived from the fermentation of grain, fruit, or molasses. One ton of dry sawdust will yield from 15 to 25 gallons of 95 per cent alcohol.

The process of producing ethyl alcohol from wood consists in general of digesting the sawdust, or hogged and shredded waste, with dilute sulphuric acid at a steam pressure of from 115 to 120 pounds for a short time. This is done in rotary digesters which will thoroughly mix the acid and wood. These digesters are of steel boiler plate with an acid-proof lining. A part of the wood is converted into a mixture of sugars, some of which are fermentable. The digested material is next transferred to a diffusion battery, similar to that used in the extraction of sugar from sugar beets or dyes from dye-wood, and here the sugar and other water-soluble material are extracted with hot water from the digested sawdust. The extract is then neutralized with lime or limestone, and the sludge formed by the calcium sulphate and some of the dust carried in the extract is allowed to settle out, which requires ordinarily from 15 to 20 hours. The clear solutions are then drained off and cooled to the proper temperature for fermentation.

The manufacture of ethyl alcohol from wood is a comparatively young industry. Under favorable conditions it is a profitable means for the disposal of wood waste.

67. Stock Food from Sawdust.—That satisfactory stock food can be made from sawdust has been demonstrated by the Forest Products Laboratory working in cooperation with the Dairy Department of the University of Wisconsin.

In preparing the food the sawdust is treated with weak acids under steam pressure in the same way as in the production of ethyl alcohol. The sugar solution formed is drawn off, and the

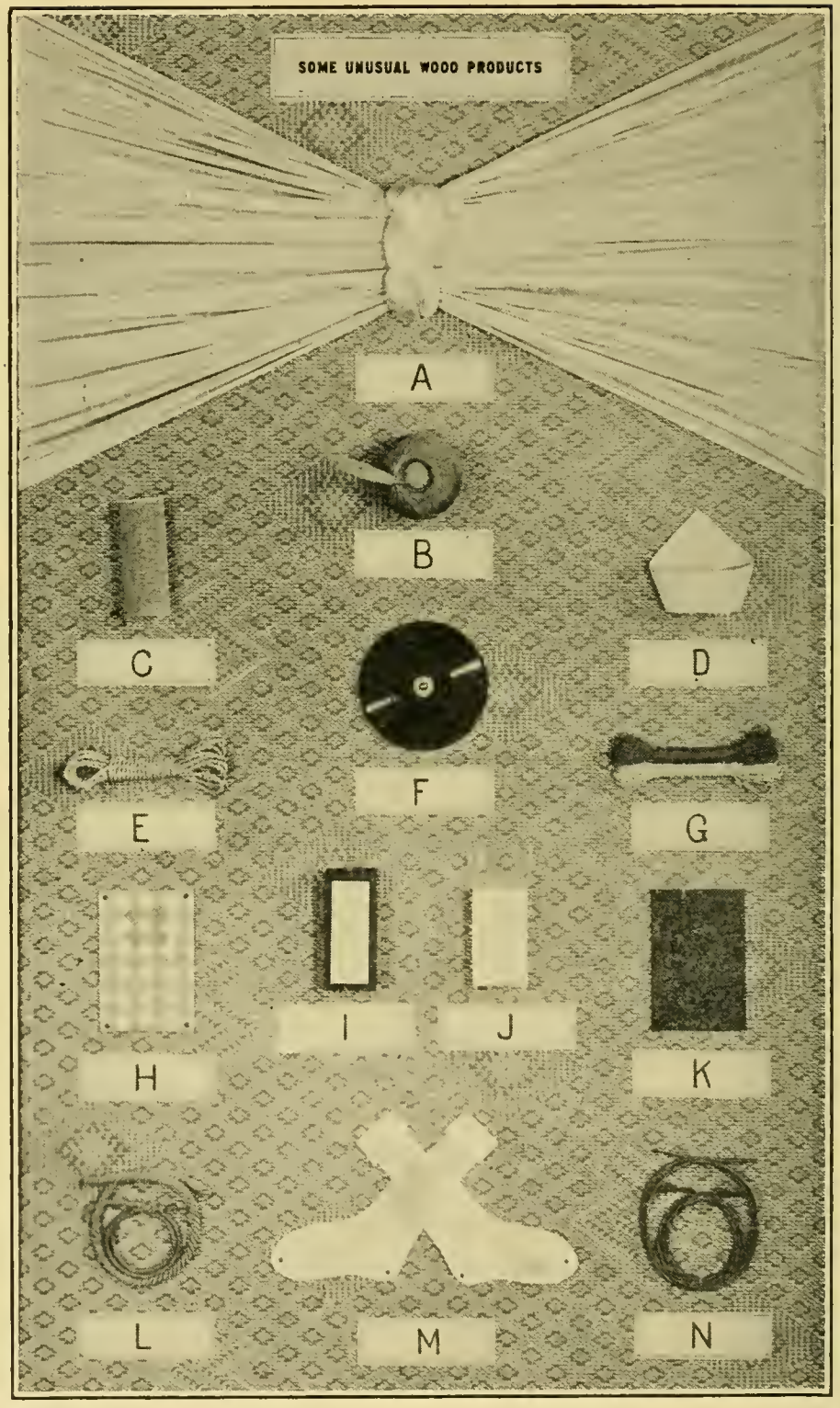


FIG. 68.—Products derived from the chemical treatment of wood. *A*, artificial silk—made from wood. The cloth is made from this silk and cotton warp; *B*, wrapping twine—made of twisted paper; *C*, paper bagging; *D*, paper webbing; *E*, paper basket braid; *F*, phonograph records—contain 60 to 70 per cent wood flour; *G*, paper rug yarn—the material covering this panel is made of paper yarn woven on linen warp; *H*, linoleum—made from wood flour and linseed oil; *I*, wood flour—finely divided wood—used in toys, linoleum, dynamite,

sawdust is washed several times to remove the acid and any sugar there may be left in it. The solution is neutralized and condensed. The leached sawdust is dried and mixed with the condensed sugar solution. By substituting sawdust treated in this way for one-third of their grain ration, cows did just as well as on a full grain ration.

68. The Ash Content of Wood.—The ash content of wood ranges from about 0.1 per cent to 6 to 7 per cent, being mostly around 1 per cent. Bark usually contains considerably more ash than wood does, as much as 12 per cent being recorded for post oak.

Wood ashes consist principally of silica, lime, potash (potassium oxide), and phosphoric acid in combination. The potash makes the ashes valuable as a fertilizer. It can be recovered by leaching the ashes with water, which is the common method of obtaining lye for homemade soap. Potash is also used in the manufacture of glass, soft soaps, oxalic acid, and to some extent in the manufacture of caustic potash.

Commercial wood ashes contain from 2 to 10 per cent of potash, although some contain considerably more. Hardwood ashes, as a rule, are richer in potash than those from conifers.

69. Other Substances Derived from the Chemical Conversion of Wood.—Artificial silk is made by dissolving cellulose from wood, cotton, or other plant material, and passing the solution through fine jets into a hardening medium. In this way fine, lustrous strands are produced which, when spun into threads and woven into fabrics, produce a very good imitation of silk.

There are three different processes of converting the cellulose into artificial silk:

(*a*) When cellulose is treated with a mixture of strong nitric and sulphuric acids, and the reaction is carried on under proper conditions of time and temperature, the lower nitrates of cellulose are formed.[1] This nitrated cellulose mixed with ether and alcohol produces a solution of greater or less viscosity depending upon the amount of solute used. On being forced through fine

[1] If the reaction is carried on under a slight change of conditions, the explosive gun cotton, which is the hexanitrate of cellulose, is formed.

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phonograph records, etc.; *J*, viscose—made from wood—used for sausage casings, aeroplane wings, envelope transparencies, etc.; *K*, shingles—this sample contains about one-third ground hemlock bark; *L*, paper ropes; *M*, socks—knit from artificial silk—sometimes reinforced at heel, toe, and top with cotton; *N*, furniture reed and braid—made of twisted paper—sometimes made with a wire cord.

jets, the ether and alcohol quickly evaporate leaving the hardened strands. On account of the inflammability of nitrated cellulose this product must be denitrated before use.

(*b*) If cellulose is first treated with strong caustic soda and then with carbon disulphide, a more or less pasty solution is formed. This is drawn out into fine threads in an acid bath or concentrated ammonium salt solution which readily coagulates it. This substance, which is called "viscose," is also drawn out into exceedingly thin sheets used for wrapping candy boxes and to some extent as sausage casings.

(*c*) Cellulose is also soluble in an ammoniacal solution of cupric oxide, and in this condition may be fibrillated into a strong acid or alkaline bath which instantly hardens it.

Celluloid is made by dissolving the lower nitrates of cellulose in a mixture of amylacetate, acetone, alcohol, and camphor, with coloring matter added. The solvents other than camphor are evaporated, and the resulting celluloid may be shaped into any desired form by the application of a moderate amount of heat and pressure. Celluloid, although closely related to gun cotton, is not explosive but burns with extreme rapidity and adds greatly to the fire hazard when present in large quantities. A noninflammable but more expensive substitute for celluloid is found in cellulose acetate.

Other products made of cellulose are artificial leather, vulcanized fiber, gun cotton, smokeless powder, and cellulose acetate varnishes.

Although the above-mentioned materials are not necessarily made from wood cellulose, their production offers an almost unlimited use for wood, especially wood waste.

Figure 68 shows some unusual products derived from the chemical treatment of wood.

CHAPTER VII

AIR SEASONING OF WOOD[1]

Air seasoning of lumber is the process of removing a large portion of its moisture by exposure to air without artificial heat. Wood is said to be thoroughly air dry when it practically has ceased to lose weight by drying under favorable seasoning conditions in the open air. Often wood is considered sufficiently air dry before this condition is reached.

70. Object of Drying.—The following are the principal reasons for air seasoning wood:

1. To reduce its weight.

Any material reduction in the weight of timber decreases the cost of handling and transportation. Often one man can handle seasoned railway ties whereas it takes two men to handle the same kind of ties unseasoned. Estimates on the cost of shipping western red cedar poles show that a reduction in weight of 12,900 pounds can be effected in seasoning a carload of 59 poles. A thousand board feet of 1-inch chestnut lumber weighs 4,600 pounds when green, and 2,500 pounds when air dry. At a 50-cent rate this means a saving of $64.50 in freight charges on a carload of poles and $10.50 on a thousand board feet of chestnut lumber. The farther that timber products are to be shipped, the more profitable it is to have them thoroughly seasoned. Obviously, from the freight charges saved must be deducted the cost of storage and extra handling and the interest on the investment which may more than counterbalance the extra freight charges on short hauls.

2. To reduce shrinking, checking, and warping after the wood is put to use.

[1] For further information on seasoning see the following:

Betts, H. S., "The Seasoning of Wood." United States Department of Agriculture *Bull.* **552.**

Humphrey, C. J., "Timber Storage Conditions in the Eastern and Southern States with Reference to Decay Problems." United States Department of Agriculture *Bull.* **510.**

Kempfer, W. H., "The Air Seasoning of Timber." American Railway Engineering Association *Bull.* **161.**

The shrinkage which takes place in thoroughly air drying wood is about one-half of the total amount of shrinkage possible in drying wood from the green to the oven-dry condition, and about two-thirds of what usually takes place in drying green wood in a kiln to 6 per cent moisture. It is obvious, therefore, that in practice there is comparatively little shrinkage after the wood is air dried.

Checking is bound to occur more or less in seasoning wood even under the best methods of drying because wood does not shrink equally in all directions, as already explained in Art. **26**; but after wood is air seasoned, no more checking should take place, except possibly a slight amount if it is kiln dried, or if the wood is placed in artificially heated buildings.

Warping is due to uneven shrinking or swelling with change in moisture content. By drying wood so that its moisture content will not change a great deal after it is in use, warping of the finished product can be eliminated, or, at least, reduced to a minimum.

3. To prepare it for kiln drying.

Although most woods can be kiln dried direct from the saw, it may be found economical and more satisfactory to allow a large proportion of the moisture to evaporate by natural seasoning.

4. To make the wood less subject to decay, discoloration, or attack by insects than if it remained in the green condition.

Ordinarily, decay will not take place in thoroughly air-dried wood as long as it remains dry, but wood which remains moist will decay sooner or later, although there is a wide variation in the resistance to decay in different species of wood. It is said of some woods that they will decay before they will season, but this is not true if the conditions for seasoning are made favorable. Some forms of discoloration take place only in moist wood. Certain wood-boring insects attack unseasoned timber, especially if the bark is left on, but they will not attack it if it is seasoned and barked.

5. To prepare it for painting or for preservative treatment.

Paint will not adhere well to wet wood, and preservatives, especially those which are of an oily nature, will not penetrate wood sufficiently unless it is seasoned

6. To increase its strength.

The influence of moisture on the mechanical properties of wood has already been discussed in Chap. V. This, however,

usually is of secondary importance, the prime objects of seasoning wood being to reduce its weight, shrinkage, and susceptibility to decay, rather than to increase its strength, stiffness, and hardness.

7. To promote combustion.

Wood used for fuel should be seasoned, or it will not only burn poorly but considerable heat will be lost in evaporating the moisture.

71. Preliminary Treatment.—Various treatments are advocated for increasing the rate of air seasoning of wood or decreasing the deterioration during seasoning. In some timber operations the trees are allowed to lie on the ground for a week or more after felling without cutting up the trunk or removing the branches. In this way some of the moisture in the trunk is evaporated through the leaves, and partial seasoning is accomplished.

A common practice in the South is to girdle cypress trees a year or so before they are felled. Cypress contains a very high percentage of moisture. After the tree is girdled, very little moisture ascends from the roots, but a large part of the moisture in the stem passes to the leaves where it evaporates. This reduces the length of the subsequent seasoning and also makes it possible to float the logs, the latter being the prime motive of girdling.

Poles and posts are usually peeled to facilitate seasoning, since bark is more or less impervious to moisture. Peeling also decreases the danger of attacks by insects.

Lumber sometimes is steamed before piling it in the yard. It is steamed at atmospheric pressure in a kiln or other suitable chamber, or in the so-called Kraetzer Process it is run into cylinders, the door closed, and a steam pressure of about 15 or 20 pounds per square inch applied for from 5 to 40 minutes. This treatment heats the lumber through. After steaming, the lumber is taken out into the yard to dry. Obviously, the heat in the lumber will cause rapid evaporation of the moisture during the first few hours of exposure, but it is doubtful whether the treatment removes any sap or starches and sugars from the wood to an appreciable extent as is sometimes claimed.

It is occasionally maintained that timber which has been in water for a long time will dry more rapidly than timber which has been kept on land, but little definite information is available on this subject. Data on the effect of soaking on the seasoning of loblolly pine cross-arms are given in Forest Service *Circular* **151,**

"The Preservative Treatment of Loblolly Pine Cross-arms," from which the following is quoted:[1]

Exhaustive experiments were made on the effect of water soaking before seasoning. It was found that there was little to be gained by immersion for different periods up to 30 days. The general results are shown in Fig. 69.

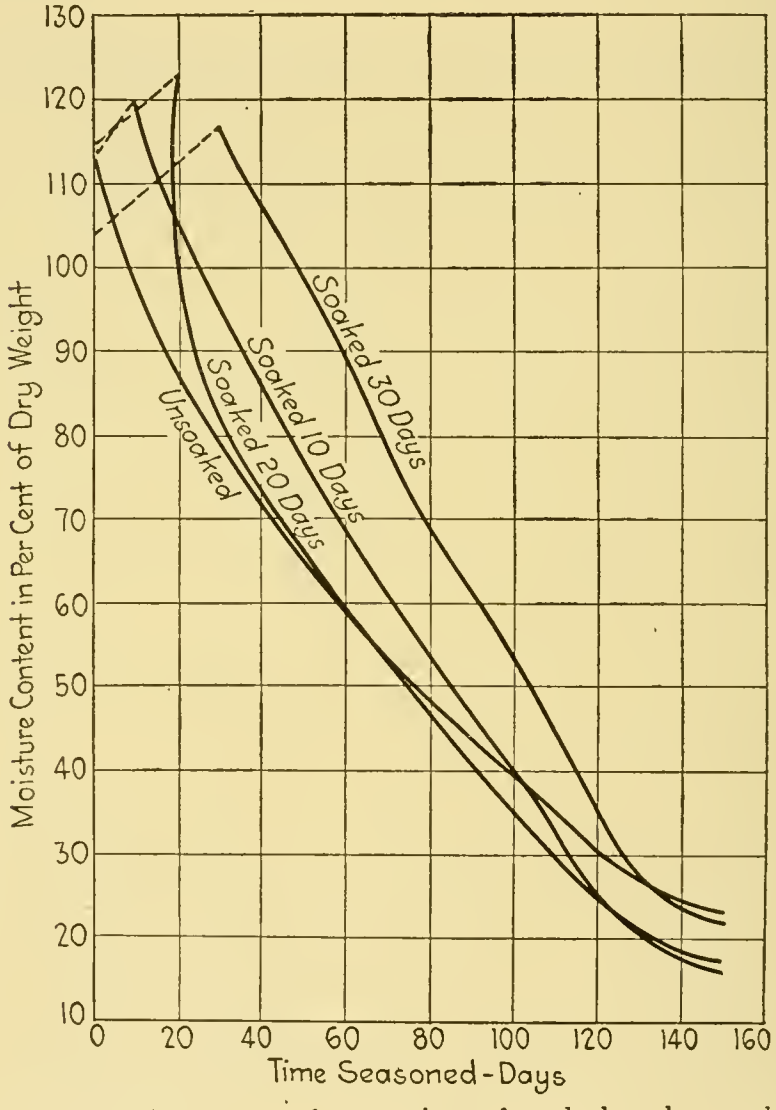

FIG. 69.—Comparative rates of seasoning of soaked and unsoaked cross-arms. (*From Forest Service Circular* 151.)

However, it should be remembered that in these experiments the longest period of immersion was one month, since it was not believed that the beneficial effect of soaking could be such as to warrant longer immersion. Had the arms been soaked for several months it is possible that wholly different results would have been obtained. So far as the

[1] By SHERFESEE, W. F.

present purpose is concerned, however, such results would have been of little practical value.

It may, therefore, be concluded that immersion before seasoning is not justified if it involves additional time and expense. The beneficial effects on subsequent seasoning, except, possibly, where the soaking is continued for prolonged periods are slight; and soaked arms do not appreciably surpass unsoaked ones in the absorption of preservatives.

Salt is sometimes sprinkled over lumber or dimension stock when it is stacked for seasoning, the purpose of the salt being to retain moisture in the surface layers and thereby reduce checking.

72. Methods of Piling.—The air seasoning of lumber or other wood products consists chiefly in arranging the pieces so that as

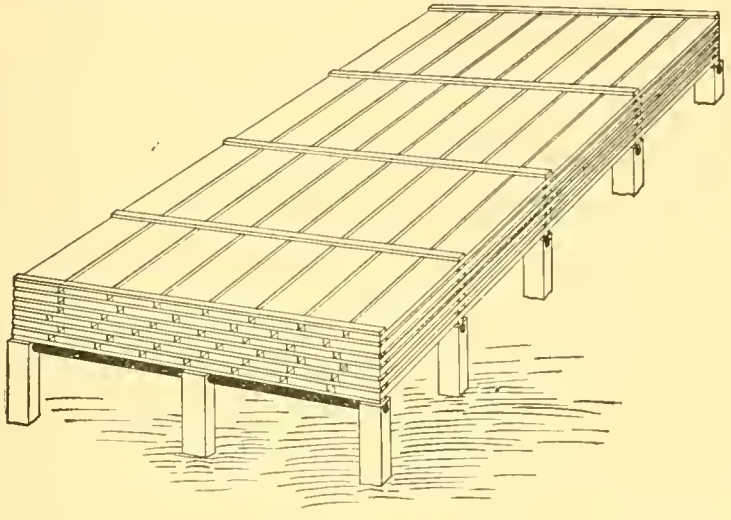

FIG. 70.—Lumber piled endwise to alley. Inflexible foundation—stickers must be placed over piers.

rapid drying from the longitudinal surfaces as is consistent with a minimum amount of degrade may be obtained. Exposure of the ends is injurious rather than beneficial, since what is gained by the more rapid drying of the ends is more than offset by severe end checking.

The main considerations in air drying are to have the material elevated above the ground, on a solid foundation, and to provide proper spacing between the members of the pile and between piles.

(*a*) *Lumber and Timbers.*—In stacking lumber or dimension stock it is piled either at right angles to the alley as in Fig. 70, known as endwise piling, or parallel to the alley as in Fig. 71 known as sidewise piling. The former is the more common. It is claimed to have the advantage of making piling and

unpiling easier, except in the case of heavy timber, of facilitating inspection and counting of the pieces, and of taking up less room, unless the piles are square. Sidewise piling is claimed to have the advantage of allowing better circulation from the alley, of allowing the rain to run across the pieces instead of lengthwise and accumulate under the stickers, and of having the ends protected against severe exposure by adjacent piles. It is assumed that in each case the pile slopes away from the alley.

The foundations of lumber piles play an important part in successful air seasoning. They should be strong and durable so that they will not sag nor give way under the weight of the pile,

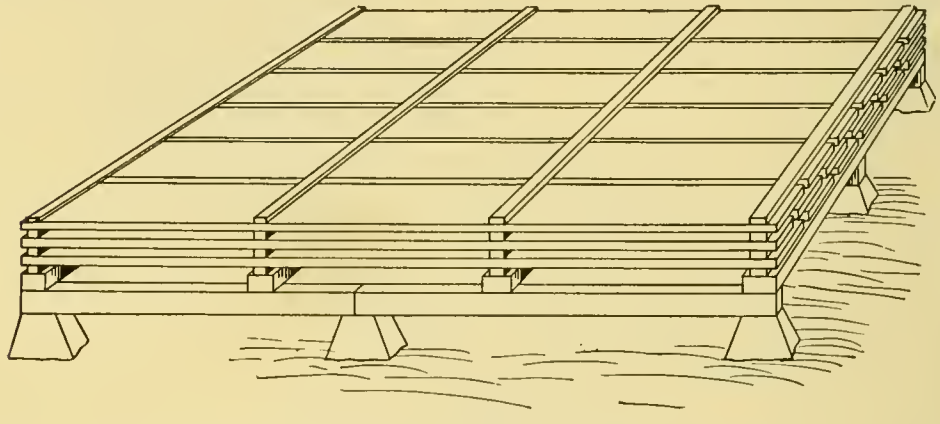

FIG. 71.—Lumber piled sidewise to alley. Flexible foundation, permitting variable spacing of stickers.

thereby twisting the lumber, and they should be of sufficient height and open so as to permit circulation of air underneath. The best kind of foundation consists of concrete or masonry piers, across the top of which are placed strong durable timbers or metal beams to carry the load as shown in Figs. 70 and 71. In a permanent lumber yard it is well worth while to go to the expense of putting in foundations of this kind. When wood is used in the foundation, it should be given a preservative treatment with creosote if possible. If this is not feasible, durable species without sapwood should be used and all points of contact should be given two coats of hot creosote applied freely with a brush. If wood which rots easily is used in the foundation of a lumber pile, it will decay in the course of a year or two, thereby not only weakening the structure but also transmitting the decay to the lumber piled on it.

The foundation should be level in the direction parallel to the alley but should have a slope away from the alley of 1 inch

in 1 foot, so as to allow the water to run off the lumber. The lowest portion of the lumber pile should be at least 18 inches from the ground.

The number of piers or other supports across the width of the pile should be enough to keep the pile from sagging between the supports. A spacing of 4 feet is close enough, as a rule, although this depends on the stiffness of the transverse skids and the weight of the pile.

The number of piers in the rows along the length of the pile depends on whether the cross pieces, or skids, over which the stickers are to be placed rest directly on the piers as in Fig. 70 or on stringers running lengthwise of the pile as in Fig. 71. If the former method is used, there must be as many rows of piers as there are to be rows of stickers. If stringers are laid longitudinally on the piers, only enough piers to keep the stringers from sagging are needed.

The use of longitudinal stringers has the distinct advantages of making the foundation suitable for various lengths of lumber and any desired spacing of stickers.

Foundations sometimes are constructed of two or more low walls of concrete or timbers running the full length or width of the piles. This form of construction greatly retards the circulation underneath and in the lower part of the piles, especially if the foundation runs parallel to the alley.

For skids and stringers the most durable and sanitary materials are I-beams or inverted railroad rails. If these are too expensive, timbers treated with creosote, as before described, are next best. Wooden transverse skids should be 4- by 6-inch timbers, and the longitudinal stringers 6- by 8-inch or larger timbers, the size depending upon the load they are to carry and the distance between supports. Fresh 2-inch strips should be placed on the transverse skids each time a pile is started.

Whenever possible, only one length of lumber should be placed in a pile. In this way no unsupported ends need be left; and when certain lengths are wanted, they can readily be obtained without repiling. If it is necessary to put different lengths into one pile, the longest ones should be placed at the bottom, or the lengths should be mixed and the pile built up square, leaving vacant places at both ends. The importance of not leaving over-hanging ends cannot be overemphasized. Thousands of dollars worth of lumber are wasted annually because of

warped ends due to improper piling. A glance at Fig. 72 shows how protruding ends will twist. This means either a total loss of several feet at the ends or a partial loss of lumber and considerable additional work in dressing down the warped pieces.

The boards in each course should be placed so as to leave a space equal to at least one-fourth of the width of the boards between the edges. The spacing of narrow strips can be simplified by placing two or three strips side by side and then leaving a correspondingly larger space between these and the next ones.

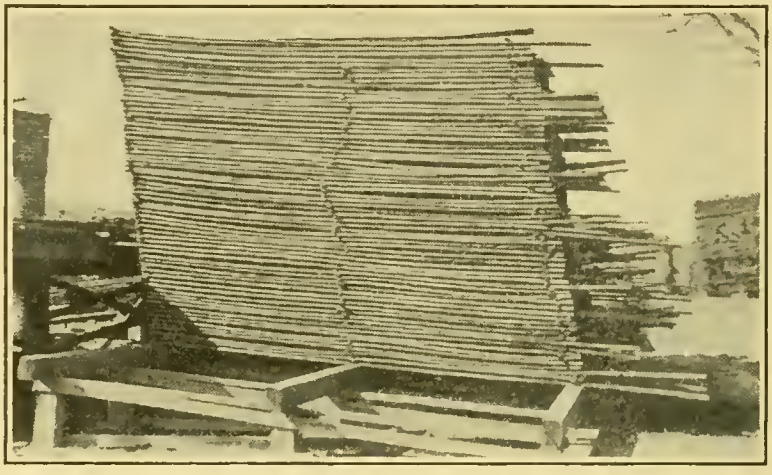

FIG. 72.—Improperly piled lumber: not enough stickers, stickers not properly aligned, too long projecting ends.

The cross pieces, or stickers, between courses should be of heartwood and dressed to a uniform thickness of $\frac{7}{8}$ inch for lumber up to 2 inches thick, and $1\frac{1}{2}$ to 2 inches for thicker material. They should be $1\frac{1}{2}$ or 2 inches wide, except for high piles of soft wood for which it may be necessary to use stickers 3 inches wide to avoid crushing the lumber under the stickers. The use of stock lumber for stickers should be discouraged unless it is not more than 3 inches wide, because wide stickers are responsible for considerable loss due to stain, decay, uneven drying, and checking between stickers. One course of stickers should be placed at each end of the lumber pile. The spacing between ends should be approximately 2 feet for all kinds of lumber thinner than $\frac{7}{8}$ inch and also for thicker lumber that warps easily, such as red gum and tupelo. For 1-inch and thicker lumber that does not warp easily the spacing should be from 3 to 5 feet. It should be borne in mind that lumber has a natural tendency to twist and cup in drying, and that it is the weight of

the lumber distributed over the stickers which keeps it reasonably straight. Care must be taken to align the stickers vertically or the lumber will become bent. Figure 72 shows the result of not placing the stickers one above the other.

In piling lumber in the open, the front, or higher, end of the pile should be given a forward pitch of 1 inch in 1 foot, except in very high piles in which the pitch should be less. A common practice is to place each sticker at the front end so as to protrude a little beyond the ends of the boards beneath it but flush with the course placed above it, as illustrated in Fig. 73. This prevents the water from running in at the higher end.

Lumber piles commonly are built from 4 to 16 feet wide, although it rarely is good practice to make them more than

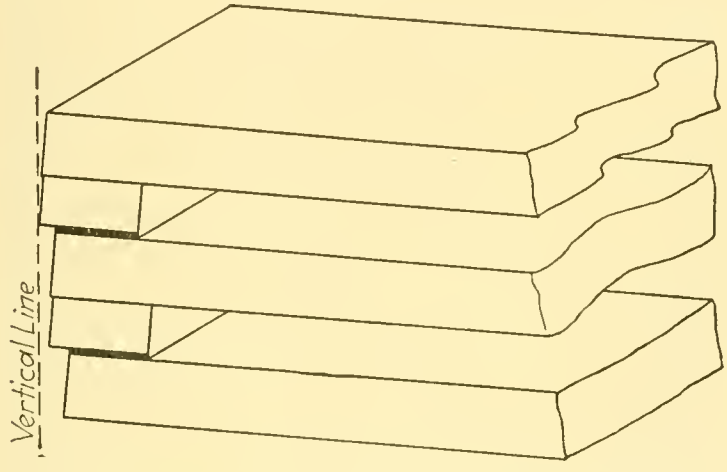

FIG. 73.—A good arrangement of boards and stickers at higher end of sloping lumber pile.

10 feet in width, especially for hardwoods. Piles more than 6 feet wide should have one or more open spaces, or "chimneys," about 1 foot in width extending upward from the bottom to two-thirds of the height of the stack. This facilitates drying at the center of the pile.

The stacks in a lumber yard should be at least 2 feet apart, and in yards which are not crowded the spacing should be 4 feet or more.

The height of lumber piles depends upon the necessity of economizing space and on the size of the material being piled. In crowded quarters stacks sometimes are built thirty or more feet in height. Such high piles, however, require very good foundations and exceeding care in piling. In yards where large quantities of lumber are handled, traveling cranes are sometimes

used for hoisting the lumber to the top of the piles and for taking it down. The lumber is first piled on the ground level in units of a thousand feet or so, and then it is hoisted up. Each unit is set off by heavy stickers so that the chains or hooks can be removed and later reinserted for unstacking. Other mechanical stackers handle the boards separately or by twos or threes as is shown in Fig. 74.

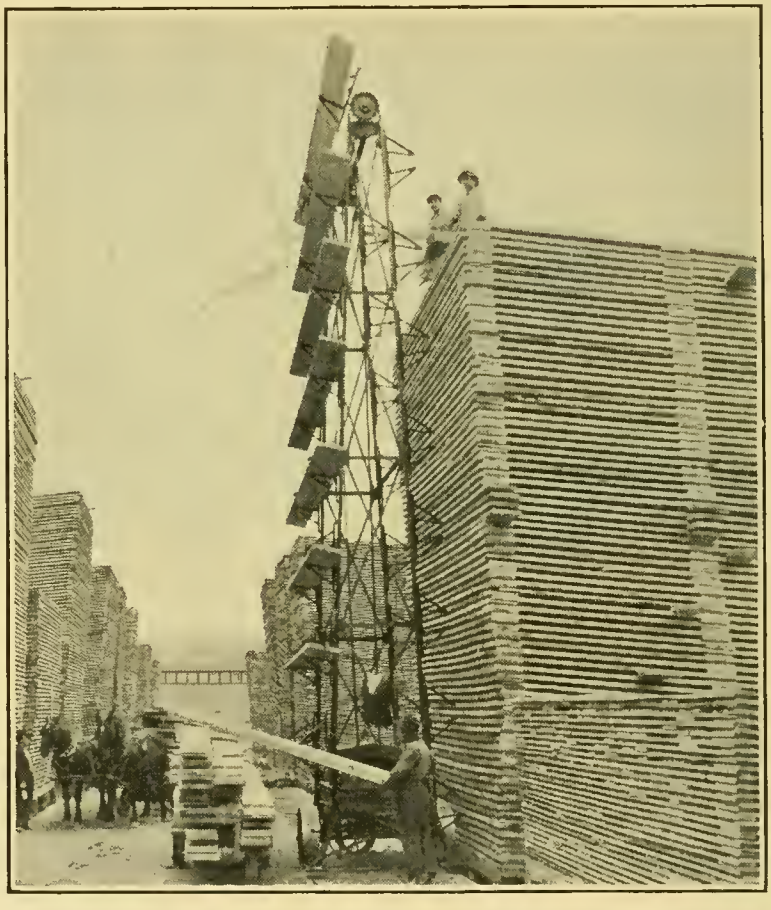

FIG. 74.—Mechanical stacker for yard piling. (*Photograph, courtesy of "Lumber" (Weekly), St. Louis, Mo.*)

The tops of piles of the better grades of lumber should be covered with roofs made of overlapping boards or of sheet metal fastened to frames. These roofs should project 1 or 2 feet on the sides and ends so as to protect the lumber from the sun and rain. It is advisable to weight or tie down these roofs so that they will not be blown off by the wind.

"Which way should a pile face?" is a question sometimes asked. The answer is that for most kinds of lumber it is preferable to have one of the sides face the direction of the prevailing winds.

If the lumber end-checks badly, however, it may be more important to have the ends face the northwest and southeast, irrespective of the prevailing wind, so as to avoid the heat of the midday and afternoon sun on the ends.

Lumber is sometimes set on edge in racks in the form of the letter X, as shown in Fig. 75. This method, which is known as pole piling, accelerates the rate of seasoning and reduces staining. Its disadvantages are that it requires a large amount of space, it requires additional work since usually the lumber is piled in stacks after it has pole dried several weeks, and woods which have a tendency to warp or cup cannot be kept straight.

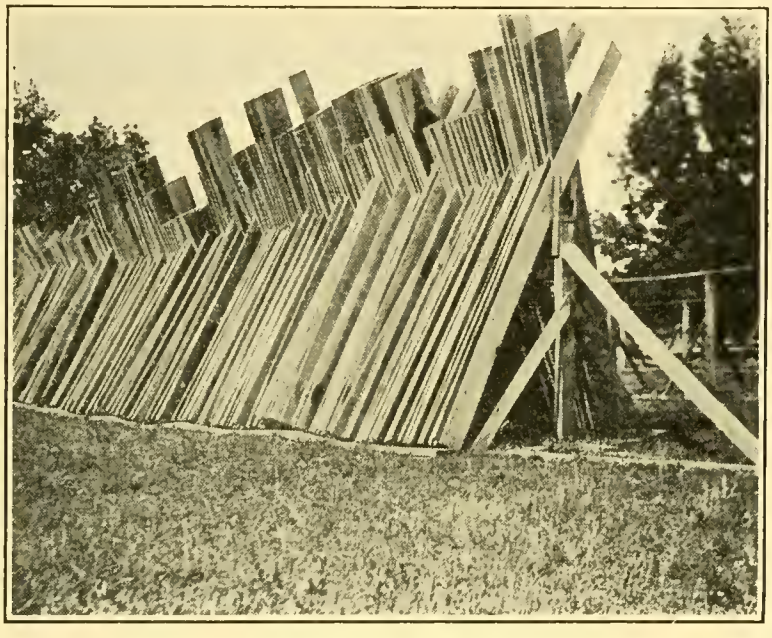

FIG. 75.—Pole piling. (*From United States Department of Agriculture Bull.* 552, "*The Seasoning of Wood.*")

Occasionally lumber is end-stacked in an open shed for seasoning, giving the appearance of a lumber pile set on end as in Fig. 76. This is practiced especially with green yellow poplar, basswood, cottonwood, and sap maple. It is claimed that end-stacking reduces staining, but there is no proof for the belief held by some that the sap runs out of the lower end and so hastens the seasoning.

Dimension stock which checks easily, such as vehicle and implement woods, is usually piled in a shed which permits of more or less ventilation. Figure 77 shows a shed which is open on one side and has a space of about one inch between the boards of the walls of the other three sides. Some sheds are

provided with doors, but openings are left at the top and bottom of the sheds for circulation of the air. In these sheds the wood is protected against the sun, rain, and hot dry winds, and as a result the seasoning is more uniform and less checking occurs than in open-air stacking.

The foundations on which lumber is piled in sheds need not slope, and the piles do not need to have a forward pitch.

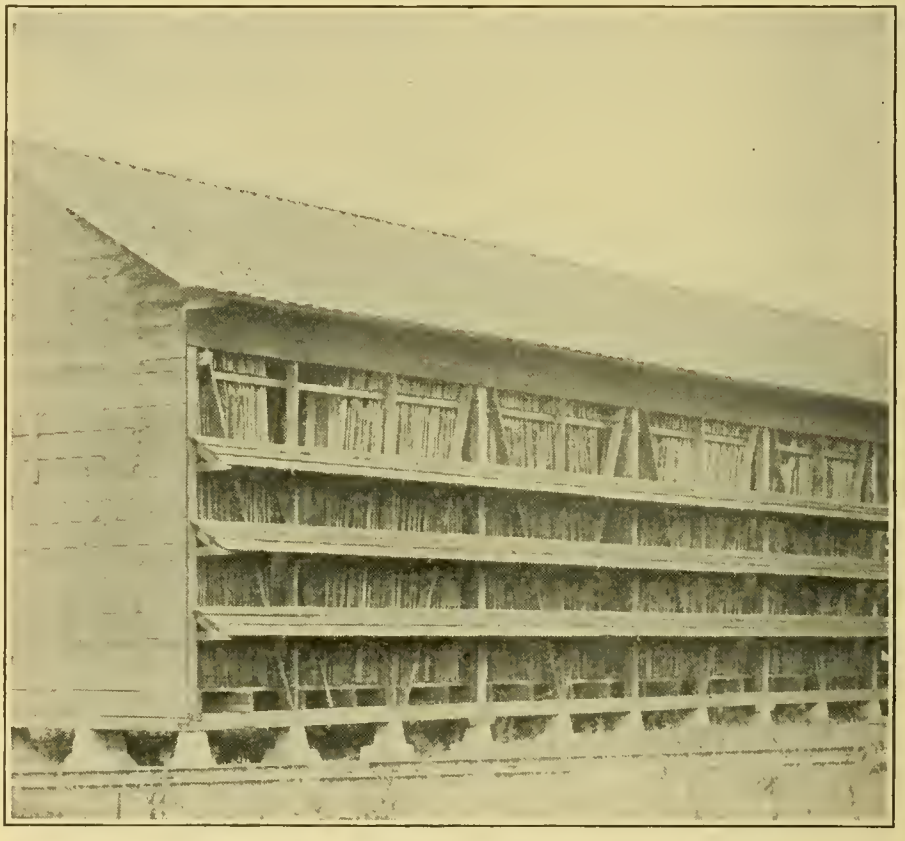

FIG. 76.—Lumber end piled in shed for seasoning. (*Courtesy, Cummer Diggins Co., Cadillac, Mich.*)

The most efficient method of handling lumber in air seasoning at factories where large quantities are used and the turnover is rapid is to load the lumber directly on dry-kiln trucks from the freight cars and allow the truck loads of lumber to season outdoors until they are moved into the kiln or shop. This requires a large number of trucks and tracks, but it saves all the handling between the car and swing saw. Figure 78 illustrates a yard where this system is used, and Fig. 79 is a diagrammatic layout of such a yard.

(*b*) *Poles.*—Electric wire poles are seasoned most rapidly if spread out in single layers on skids. Seasoning will be much

retarded if the poles are stacked in solid piles. If solid piling is used in a warm, moist climate, decay or injury by wood-boring insects is likely to occur if the poles are held for any considerable period.

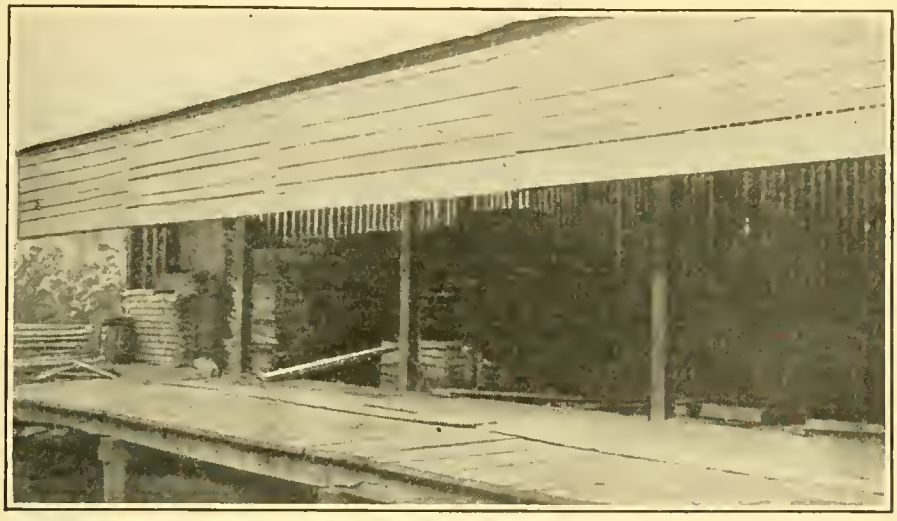

FIG. 77.—Shed with one open side for drying vehicle dimension stock. Note cracks between boards on other walls.

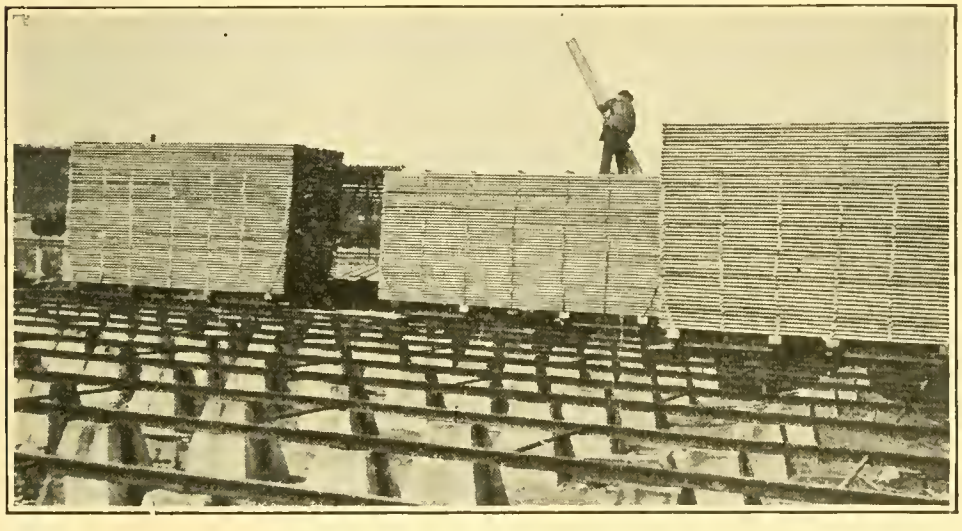

FIG. 78.—Lumber stacked in yards on trucks. An ideal way of storing lumber before kiln drying. (*Courtesy, Nordyke & Marmon Co., Indianapolis, Ind.*)

(*c*) *Posts and Railway Ties.*—Posts and ties are placed in piles to facilitate seasoning and to economize space. The piles should never be solid, however, unless the wood has been given a preservative treatment with oil. Moisture will enter a solid pile far more readily than it can be evaporated. An effective and practical method of piling posts and ties is to pile them in alternate

layers of two and seven as illustrated in Fig. 80. Sometimes an equal number is put in each layer. This form of pile can be improved greatly by setting the outer ties of each layer on edge,

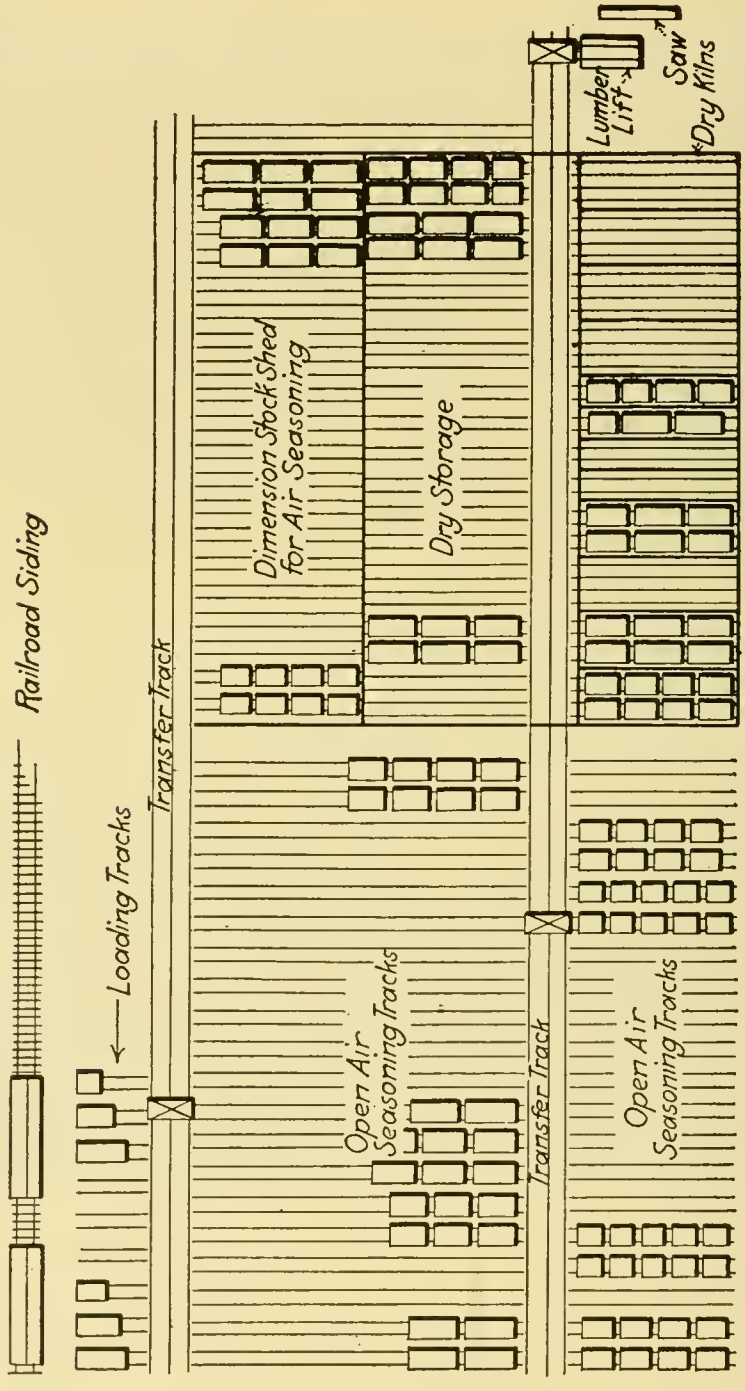

Fig. 79.—Layout of model lumber yard and kilns in which all lumber is moved on trucks from car to saw.

if they are square edged, and, in the case of posts, by placing the thicker ones toward the outside. This allows the air to come in contact with the top and bottom of each piece within the

pile. This method is satisfactory if the piles are well exposed; but if they are close together, or the circulation of air is hindered by bushes or buildings, they should be as open as possible. In any event, space should be left between the posts or ties in each layer, and proper foundations should be supplied.

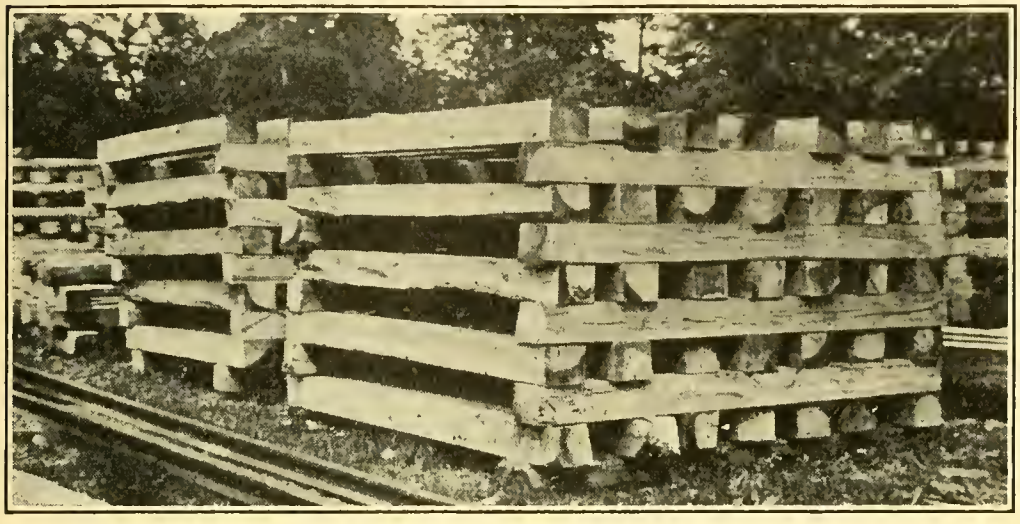

FIG. 80.—A good method of piling green ties.

73. Sanitary Precautions in and about the Lumber Yard.—Green or partly seasoned wood is in a favorable condition for decay. The fungi which cause decay readily spread from one piece to another by means of spores blown about by the wind and by direct contact of a sound piece with decaying wood. In a lumber yard where wood is seasoning, it is highly important, therefore, to keep the yard as free from rotting wood as possible so as to decrease the chances of infecting the lumber before it is dry enough to be immune from decay. After lumber once is thoroughly air dry it will not decay so long as it is kept in that condition.

If lumber is piled so that it cannot season properly, or if sound, green lumber is piled on decaying foundations, and is left in this condition for several months of warm weather, it may become rot infected sufficiently to weaken it seriously. Hence, it is essential that foundations be made of material which does not deteriorate quickly and that all debris of any kind be removed from places where lumber is stored. Even the black surface soil should be removed, and gravel or, better yet, cinders substituted in order to have a first-class sanitary lumber yard. Weeds should not be allowed to grow about the base of lumber

piles as they obstruct the circulation under the piles and in the lower courses. The following quotation from Humphrey[1] emphasizes the importance of adopting sanitary measures.

The vital necessity for absolute cleanliness, from the standpoint of leaving decayed wood around yards to harbor fungi and spread decay, is not sufficiently appreciated by most lumbermen. The debris may consist of rotten ties, old tramway timbers, decayed foundation blocks,

Fig. 81.—A dirty, highly insanitary lumber yard. Note the rotten ties and other debris scattered about to breed infectious fungi. (*Courtesy, C. J. Humphrey, Bureau of Plant Industry.*)

and even timber stock which has rotted in piles on the yard. Such refuse should be collected and burned in all cases. Many yards recognize the extra fire hazard which this occasions and take steps to prevent its accumulation, but under most circumstances the scrutiny is not close. In a few yards apparently no attention at all is paid to the matter. A glance at the illustration (see Fig. 81) depicting conditions at one mill in the East will suffice.

All yards should safeguard their stock by keeping their storage grounds scrupulously clean. The work can be assigned to a certain set of workmen, say, the repair gang, who should be held strictly accountable.

[1] Humphrey, C. J., "Rot in Stored Lumber." *American Lumberman*, Aug. 14, 1915.

Whenever possible to avoid it, timber should never be piled over swampy ground, as is frequently done in the coastal regions, and, further, yards should not be filled in with sawdust, bark debris, and "hogged" slabs in lieu of dirt.

74. Deterioration while Seasoning.—The extent of deterioration which takes place in seasoning lumber depends upon the kind of wood and the care it receives in the yard. Some forms of deterioration can be prevented entirely, whereas at best, others can be eliminated only in part. The following are the chief defects which may occur while lumber is air seasoning.

(*a*) *Checking.*—Little can be done to prevent surface checking in air seasoning. Lumber must be open piled in order to dry out, and when so piled it is apt to surface check during dry weather. Woods which check badly, such as vehicle woods, are often seasoned in sheds to reduce the checking as much as possible. Sometimes lumber is piled in solid piles to prevent surface checking, but this is poor practice since it induces conditions favorable for decay.

End checking can be reduced by shading the ends of the piles, by coating the ends, or by nailing wooden or metal strips across the ends. Methods of preventing end checking have already been described in Art. **26.**

(*b*) *Twisting and Cupping.*—These can be avoided largely by using sufficient stickers and leaving no unsupported ends.

(*c*) *Casehardening and Honeycombing.*—Practically nothing can be done to prevent these in air seasoning in species subject to these defects. If the lumber is piled close together, casehardening and honeycombing will not occur, but the lumber will not dry, and decay may set in.

(*d*) *Sap Stain.*—This is a fungous growth which lives on the sap in the sapwood during warm weather. As soon as the lumber dries out, the fungus dies or becomes dormant. Sap-stain cannot always be prevented by air seasoning, but it can be reduced by piling the lumber so that it will dry out rapidly. At some mills yellow pine sapwood lumber is dipped in a soda bath as it comes from the saw to prevent or to reduce staining. This is discussed more fully in Chap. IX. Kiln drying wood from the green condition will prevent the blueing of sapwood.

(*e*) *Decay.*—If lumber does not dry, the heartwood of many species and the sapwood of all will decay in a comparatively short time in warm weather. If lumber is close piled, or other-

wise kept from seasoning, non-durable kinds will decay enough in three months, and possibly less, of summer weather to make them brittle and brash. Wood which has a moisture content of less than 18 or 20 per cent is not subject to decay so long as it is kept in that condition.

(*f*) *Insect Attack.*—During the warm seasons many woods, especially hardwoods, while unseasoned, are subject to attack by wood-boring insects. Rapid seasoning often is the only practical remedial measure that can be taken, although under certain conditions other treatments, such as spraying with a kerosene-creosote mixture, may be advisable. The sapwood of ash, elm, hickory, oak, and a few other species even when seasoned is attacked by the powder-post beetle.

75. Time Required for Seasoning.—A number of factors influence the time required for air seasoning, the most important of which are the weather, the time of year, the size of the material, the kind of wood, the manner of piling, preliminary treatment, and the degree of dryness desired. Anything which hinders the drying either increases the amount of stock held on hand or the cost of handling and transportation.

Obviously, dry, warm weather and a good circulation of air cause the most rapid evaporation of moisture. Freshly cut ties of some species have been found to lose as much as 10 pounds of water in the first 24 hours of seasoning. The extent to which favorable drying conditions prevail depends upon the part of the country and the season of the year. In the arid Southwest, timber dries out much more quickly than in the more humid sections of the country. According to data obtained by the Forest Service, yellow pine ties cut in May or June in New Mexico lost about 70 pounds in weight in one month, and were fairly well seasoned in 1 to 2 months; while loblolly pine ties at Silsbee, Texas, cut at about the same time of the year, lost only about 37 pounds in the first month and required 3 months to reach about the same degree of seasoning. This difference is due to the higher humidity prevailing near the coast of Texas. Experiments made on Douglas fir ties at Tacoma and Pasco, Wash. showed considerable difference in the rate of seasoning, the latter place being east of the Cascade Mountains and away from the humid conditions prevailing near the Coast. The ties at Pasco not only lost weight faster but reached a lower moisture content than those at Tacoma.

The changes in the drying rate at different seasons of the year in any one part of the country are greater than the differences in the drying rate in the various parts of the country at corresponding periods of the year. Each region has its favorable and unfavorable periods for rapid drying, the winter months, or rainy season, being the most unfavorable. Timbers partly seasoned before the beginning of the unfavorable period may cease to give off moisture, or even take up moisture, during this period; but if cut during the cold or wet months of the year they usually begin to lose moisture at once although at a slow rate,

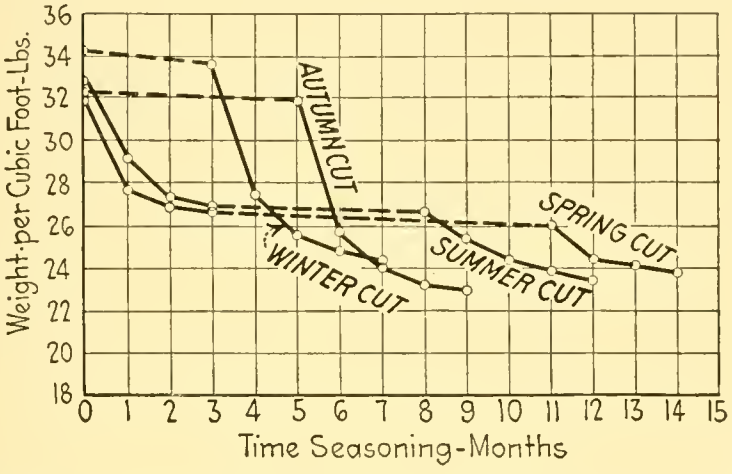

FIG. 82.—Seasoning of northern white cedar poles at Escanaba, Mich. (*From United States Department of Agriculture Bull.* 552, "*Seasoning of Wood.*")

so that when warm, dry weather comes on they are already partly seasoned.

Whether spring-, summer-, autumn- or winter-cut wood becomes thoroughly air dry most quickly depends largely upon the size of the pieces. It has already been pointed out in Art. **21** that the amount of moisture in live timber is practically the same throughout the year, and, therefore, this does not influence the time required for seasoning. Material which will season in 2 to 4 months will reach its minimum moisture content most quickly if cut at the beginning of the dry season, which usually occurs toward the end of spring. Larger pieces, as poles and timbers which require a longer period of dry weather for seasoning, will not become air dry the same year if cut in the spring or summer and must be carried over to the next summer in order to become thoroughly dry; if cut in the autumn or winter, however, they may be sufficiently air seasoned at the end of the following summer as is shown in the curves in Fig. 82.

The time of the year in which wood is cut may be more important from the standpoint of deterioration than from the time required for seasoning. Timber cut in the summer dries quickly in the surface layers which causes them to check or caseharden while the interior is still wet. As a consequence, dimension stuff and lumber are seriously weakened and lowered in grade. Wood cut in late autumn or winter dries out more slowly and uniformly, thereby reducing the amount of checking. Furthermore, timber cut during the cooler months is not subject to immediate attack by decay or insects, nor is it subject to stain as a rule.[1] This statement does not hold for regions having a mild, damp winter as in certain parts of the West Coast where it has been found that the deterioration in sugar pine lumber from stain and other causes is approximately 71, 38, and 16 per cent for the fall, spring, and summer drying respectively.

Certain data on timbers show that the size of timbers has a marked effect on the rate of seasoning, but the effect is not so great as might be expected. For instance, 5- by 8-inch shortleaf pine timbers lost 71 per cent of their total loss in 60 days of seasoning, and 8- by 12-inch timbers of the same species and approximately same initial moisture content lost 67 per cent of their total loss in the same length of time; and at the end of 15 months' seasoning the smaller size had only 3 per cent less moisture than the larger size.[2] This difference is not at all proportional to the amount of surface exposed. Western hemlock bridge stringers near Seattle were found to reach a fairly constant moisture condition in about a year, while sticks 2 by 2 by 30 inches were thoroughly air seasoned in 60 days of favorable weather.

Short pieces like firewood, hub blocks, and stave bolts dry more rapidly than long pieces on account of the larger amount of end surface exposed in proportion to the volume. In timber, poles, and lumber the evaporation takes place mostly from the sides, which is much slower than from the ends.

The kind of wood and whether it is mostly heartwood or sapwood have an important bearing on the time required for seasoning. In general, hardwoods season more slowly than conifers, although cypress is more like the former in this respect. Chestnut poles in Pennsylvania contained about 46 per cent

[1] The influence of the time of the year on the deterioration of lumber will be discussed in more detail in Chap. IX "Deterioration of Wood."

[2] KEMPFER, W. H., "The Seasoning of Wood."

moisture after 2 years' seasoning while southern white cedar poles in North Carolina contained only 26 per cent after 17 months' seasoning. Differences in the rate of seasoning may be due to differences in the original moisture content or in the ease with which the moisture comes to the surface. The latter, probably, is the more influential factor. Eucalyptus lumber, which is probably the most difficult to season, requires 3 years' time before it is considered fit for the more exacting classes of work. Oak lumber usually is air seasoned 1 to 2 years, tupelo gum 6 to 12 months, red gum 3 to 6 months, and birch and yellow pine 2 to 4 months. After air seasoning, much lumber is kiln dried to remove still more moisture.

Sapwood allows water to pass through it more readily than heartwood, and, therefore, loses moisture more rapidly. Although green sapwood usually contains more moisture than green heartwood yet, as a rule, it will air season just as rapidly, or even more so, than the heartwood. This is well illustrated in the seasoning of loblolly pine cross-arms in which the heart-arms contained 51.5 per cent moisture when cut and the sap-arms 105.8 per cent. However, in 34 days they were both reduced to the same moisture content.

Bark is very impervious to moisture and if left on posts, poles, and ties it reduces considerably the rate at which they season besides increasing the danger of attack by insects. On the other hand, bark reduces checking by not allowing the surface to dry too rapidly which is of advantage, especially in saw logs.

The manner of piling lumber determines the accessibility of air currents and, therefore, the rate of seasoning. Suggestions for proper piling have already been made in Art. **72.** Determinations made by the Forest Service show that if the piles are isolated, the influence of the character of the piling on the rate of seasoning is slight, provided, of course, the pile is not solid. Tests on lodgepole ties at Sheridan, Wyo., showed that ties in open crib piles (seven and two in alternating layers) lost more than twice as much water in 3 weeks than ties piled solid (nine in each row). The closer the piles are together, however, the more open each pile ought to be. Observations on the rate of seasoning of loblolly pine cross-arms at a tie-treating plant in Norfolk, Va. showed that cross-arms piled with air spaces on all sides of each arm dried out to a weight of 34.1 pounds per arm in a little less than 6 weeks, while those piled with air spaces only

above and beneath and none on the sides required more than 16 weeks to reach the same weight. Other conditions that will retard the circulation of air, as piling lumber so that it will be protected by a ridge or trees, will also reduce the rate of seasoning.

While it is claimed that preliminary treatments such as described in Art. **71** hasten the rate of drying materially, little definite data are available on the subject.

The degree of dryness desired influences the time of seasoning materially because it takes much more time to extract the last 5 per cent or so of water than the first 5 per cent. When wood is dried merely to reduce the shipping weight, low stock may prompt the manufacturer to send out the lumber with comparatively little seasoning.

Sometimes we hear of woods being air-seasoned an unusually long time for certain high-grade articles. Vehicle and implement makers dry their stock in sheds or out-doors for two to five years. Willow blocks for artificial limbs are seasoned up to three years, and woods for musical instruments as much as seven years. No accurate data are available to show whether such long periods of seasoning are justifiable. The good reputation of woods seasoned an unusually long time is probably due to an adjustment of stresses which develop in the wood during seasoning. Many fibers may be under tension or compression which is not sufficient to rupture the wood, but which in the course of time, like a spring long held under tension, lose most of their power to change their shape when relieved.

76. Degree of Dryness Attainable.—The per cent of moisture left in wood after it is thoroughly air-dried under favorable conditions varies chiefly with the size of the material and the climate. Theoretically, the size of the pieces should make little difference in the ultimate dryness attained, but in practice it is found necessary to consider large timbers air-dry long before they have reached the minimum moisture content. Forest Service records show that western larch bridge stringers 8 by 16 inches were still losing in weight after 3½ years of seasoning, and western hemlock and redwood timbers after 3 years. Practically, these woods might have been considered air dry after from 1 to 2 years of seasoning. Figure 83 shows the distribution and average per cent of moisture in large timbers and car sills of western larch after seasoning for various periods. The smaller timbers contained 4.4 per cent less moisture than the larger ones

after seasoning had practically come to a standstill. Large stringers of redwood were considered air dry when the interior still contained 33.2 per cent moisture, while smaller sizes, such as joists, 2 by 8 inches, contained only 13.5 per cent when considered air seasoned.

Hemlock ties cut at Escanaba, Mich., had a moisture content of 27.5 per cent after passing through two full seasoning periods,

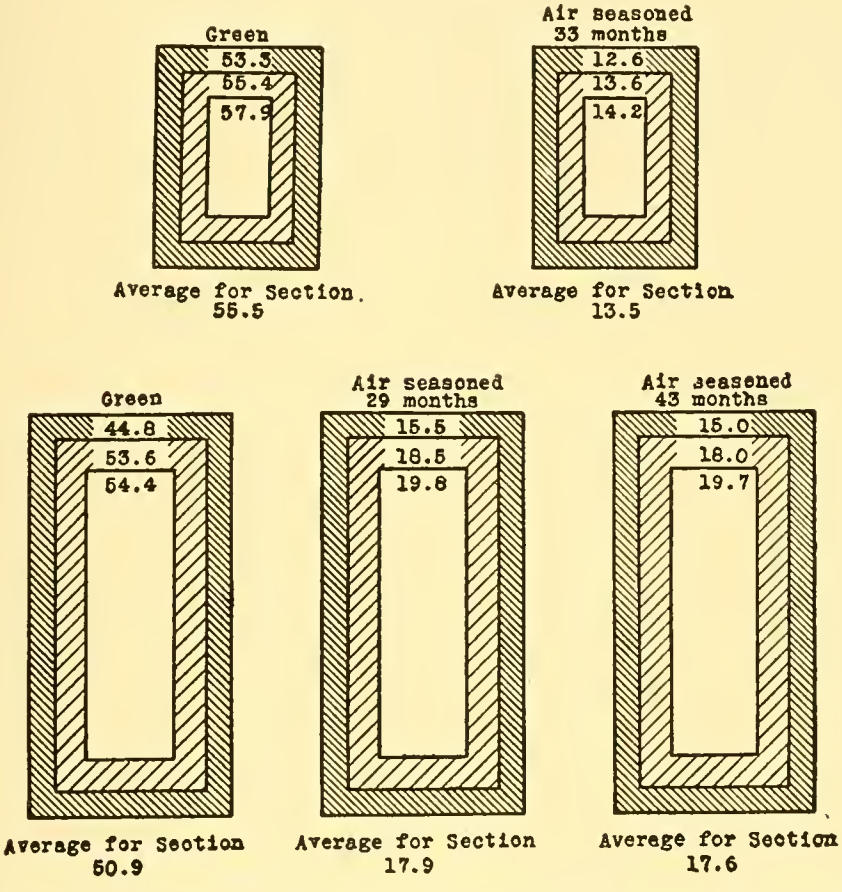

FIG. 83.—Summary of moisture determination made upon green and seasoned bridge stringers and car sills of western larch. (*From Forest Service Bull.* 122 "*Mechanical Properties of Western Larch.*")

while hemlock sections 3 inches thick cut from some of the ties at the same time reached an average moisture content of 15.4 per cent.[1] The ties would probably have lost some more moisture the third summer, but the loss would have been so slight as to be practically negligible.

The moisture contents of small dry blocks 1½ by 1½ by 8 inches of various woods as determined by Tiemann at New Haven,

[1] These figures are not fully comparable but indicative, for the ties were not protected from the weather, while the 3-inch sections were stored under a roof.

Conn. are shown in Table XIX. These blocks had been seasoned more than 1 year in a shed on the north side of a building. The determinations, which were made after 5 days of dry weather, showed a moisture content of from 13.3 to 15 per cent. It is interesting to note that the variation between different species was not great and that white pine and spruce, two woods much alike in many respects, showed extremes in moisture content. In dry climates or after prolonged very dry weather in the greater part of the United States the moisture content may go as low as 10 per cent or even lower, while in very damp regions the minimum average moisture content obtainable even in small stock is 17 or 18 per cent. The relation of the humidity of the air to the ultimate moisture content of wood has already been discussed in Art. **22.**

TABLE XIX.—MOISTURE CONTENT OF SMALL BLOCKS THOROUGHLY AIR-SEASONED AT NEW HAVEN, CONN.

Wood	Per cent	Wood	Per cent
Longleaf pine	13.3	White ash	14.4
Loblolly pine	14.7	Hard maple	14.9
Red spruce	15.0	Brown ash	14.9
White pine	13.4	Red gum	14.9
Red fir	14.1	Chestnut	13.8

CHAPTER VIII

KILN DRYING[1]

Kiln drying is the process of artificially seasoning lumber by applying heat to it in an enclosed space, or kiln. It shortens the time required for seasoning, and, if done properly, it may turn out a better and more suitable product than ordinary air drying. Kiln drying is widely practiced in connection with the manufacture and utilization of the better grades of lumber. At some plants all grades are kiln dried.

77. Purposes of Kiln Drying.—The principal purposes of kiln drying are:

1. To remove the moisture more rapidly than can be done in air drying, thereby reducing the quantity of lumber it is necessary to carry in stock, or reducing the freight charges if the lumber is to be shipped soon after sawing.

Under many conditions it pays to kiln dry lumber green from the saw instead of using the slow process of air seasoning. Where air drying requires several months, kiln drying can be accomplished in several days; where air drying requires 2 or 3 years, kiln drying reduces the time required for seasoning to 3 or 4 months. Speed is an essential of modern business. A rapid turn-over of stock makes for efficiency and flexibility of operation. With the increasing cost of lumber and labor, air seasoning becomes more expensive because of the large amount of

[1] For more detailed information on the subject of kiln drying lumber the reader is referred to the following:

THELEN, ROLF, "Kiln Drying Handbook." United States Department of Agriculture *Bull.* **1136.**

TIEMANN, H. D., "The Kiln Drying of Lumber." J. B. Lippincott and Co., Philadelphia, Pa., 1917.

TIEMANN, H. D., "The Principles of Drying Lumber at Atmospheric Pressure, and Humidity Diagram." Forest Service *Bull.* **104.**

TIEMANN, H. D., "The Theory of Drying and Its Application to the New Humidity-regulated Dry Kiln." United States Department of Agriculture *Bull.* **509.**

KOEHLER, ARTHUR, "The Kiln Drying of Lumber." Correspondence-Study Course, Extension Division. University of Wisconsin.

capital required to carry the stock through the seasoning period, and because of the extra labor required in stacking it. The cost of kiln drying, however, does not increase in like proportion.

Whenever there is a shortage of lumber on the market, it may be out of the question to stop to air season the lumber before it is shipped from the mill. In such cases the removal of most of the moisture by kiln drying may save more in freight charges than it would cost to dry the lumber.

2. To reduce the moisture content of wood below that attainable in air drying so that further drying and shrinking will not take place after it is put into use.

The moisture content of lumber considered thoroughly air dry commonly ranges from 12 to 18 per cent; usually it is closer to the higher figure. Such lumber will lose still more moisture and shrink during extremely dry seasons, or when exposed in a heated room, thereby causing the wood to warp and check, and the joints to open up. Therefore, it is necessary for many purposes, to dry lumber artificially to below 12 per cent; for example, furniture, interior finish, and parts of vehicles. Thoroughly kiln-dried wood should contain from 4 to 12 per cent moisture, according to the purpose for which it is to be used. It is better to have lumber absorb a little moisture when in use than to have it dry out a great deal, since a little swelling is usually not so detrimental as a little shrinking. Lumber may be over dried and, therefore, the drying should be stopped at the proper time.

Kiln drying is also practiced to reduce the moisture content below that attainable in air drying in order to reduce the shipping weight to a minimum.

3. To avoid or reduce injuries to the lumber, such as checking, honeycombing, staining, and insect attack, which may occur in air seasoning.

In air drying, considerable lumber is degraded by checking and warping because of the uneven exposure to the drying influences of sun and air currents. This loss can be reduced in many species by kiln drying the lumber green from the log. Western yellow pine checks so badly in air drying in California that it pays to kiln dry all grades. Sap stain, which is a blue discoloration of the sapwood of the pines, red gum, and other species, caused by a fungus, can be prevented by kiln drying the lumber direct from the saw.

4. To harden the resin by evaporating the volatile matter.

Heating resinous woods draws some of the turpentine and resin to the surface where the volatile oils are evaporated and resin is deposited. This deposit of resin is later removed by surfacing, leaving only a little hardened resin in the lumber.

5. To make the wood more suitable for gluing and painting. It is well known among wood workers that if lumber is not dried to a proper moisture content it will give trouble in gluing on account of the shrinking or swelling which may take place after the glue is applied. Paint, varnish, shellac, etc. stick best on thoroughly dry wood. Furthermore, if the wood is not sufficiently dry before coating it, subsequent shrinkage will cause checks and other unsightly gaps where moisture and decay can enter later.

Another advantage, but hardly a purpose of kiln drying lumber, is that it reduces the "working" of wood with changes of atmospheric humidity. As stated in Art. **22,** wood exposed to high temperatures loses some of its power to absorb moisture from the atmosphere. For this reason, wood kiln dried at high temperatures will not shrink and swell quite so much with changes in atmospheric humidity as woods not so treated.

78. Theory of Kiln Drying.—The drying of lumber involves two steps: (1) The passage of the moisture from the interior of the wood to the surface; and (2) the evaporation of the moisture from the surface. *Heat* hastens both these processes. Supplying a sufficient amount of heat, therefore, is the first essential of artificial drying. This is done by confining the lumber in a kiln and heating the air (or steam, if superheated steam is used) surrounding the lumber. Some of the heat passes from the air to the lumber and warms it through; some is used in evaporating the moisture from the surface of the lumber; some is retained in the air to hold the evaporated moisture which is later expelled from the kiln or passed through the condensers; and some is lost by radiation through the walls, ceiling, and floor.

Since the air surrounding the lumber loses its heat in a number of ways, more heated air must continually be supplied in order to keep up a certain temperature within the piles of lumber. Furthermore, the air becomes laden with moisture which must be removed or no more drying will take place. This means that there must be a movement or *circulation* of air in the dry kiln.

High temperatures and a circulation of comparatively dry air will cause the moisture to be evaporated very rapidly from

the surface of the lumber; in fact more rapidly than the moisture may be able to travel from the interior to the surface. Consequently, excessive surface drying with attendant checking, casehardening, and slower drying may result. To obviate these objectionable features the air in the kiln must not be allowed to become too dry; that is, it must have a certain *humidity*.

Three conditions, therefore, are necessary to the kiln-drying operation; namely, a certain degree of heat, thorough circulation,

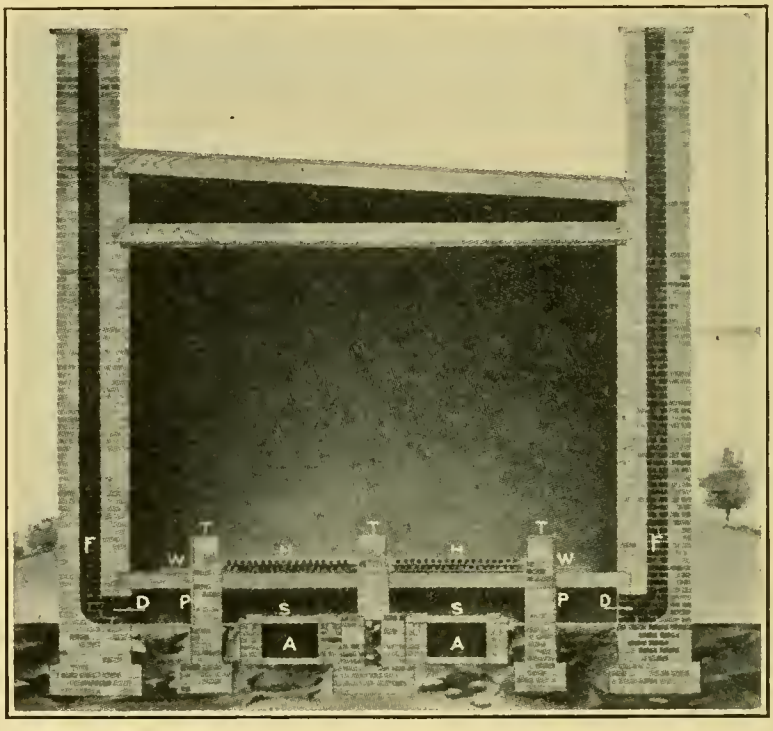

Fig. 84.—Cross-section of American Blower Company's natural circulation compartment kiln. *H*, heating coils; *A*, fresh-air inlets; *F*, flues; *D*, dampers; *S*, slots in top of fresh-air ducts; *P*, partitions; *W*, walks; *T*, supports for lumber.

and a certain amount of humidity in the air. To make possible these conditions it is necessary to have the lumber properly piled, and enclosed in a properly constructed kiln.

79. Kinds of Kilns.—Dry kilns may be divided into two classes with regard to construction and operation; namely, compartment and progressive kilns. In the compartment, stationary charge, or box kilns as the small ones are called, the aim is to keep the drying conditions uniform throughout the kiln, and to change the conditions from time to time to fit the needs of the lumber as the drying proceeds. When all the lumber is dry, it is removed and the kiln is filled with a new charge.

In the progressive type of kiln the air in one end is comparatively cool and moist while the air in the other end is hot and dry, with a gradual change of conditions between the ends. Lumber is put in at the moist, or "green," end and progressively moved toward the dry end from which it is removed when sufficiently dry. Ordinarily, the kiln is kept full of lumber; therefore, all stages of drying may be found within the same chamber.

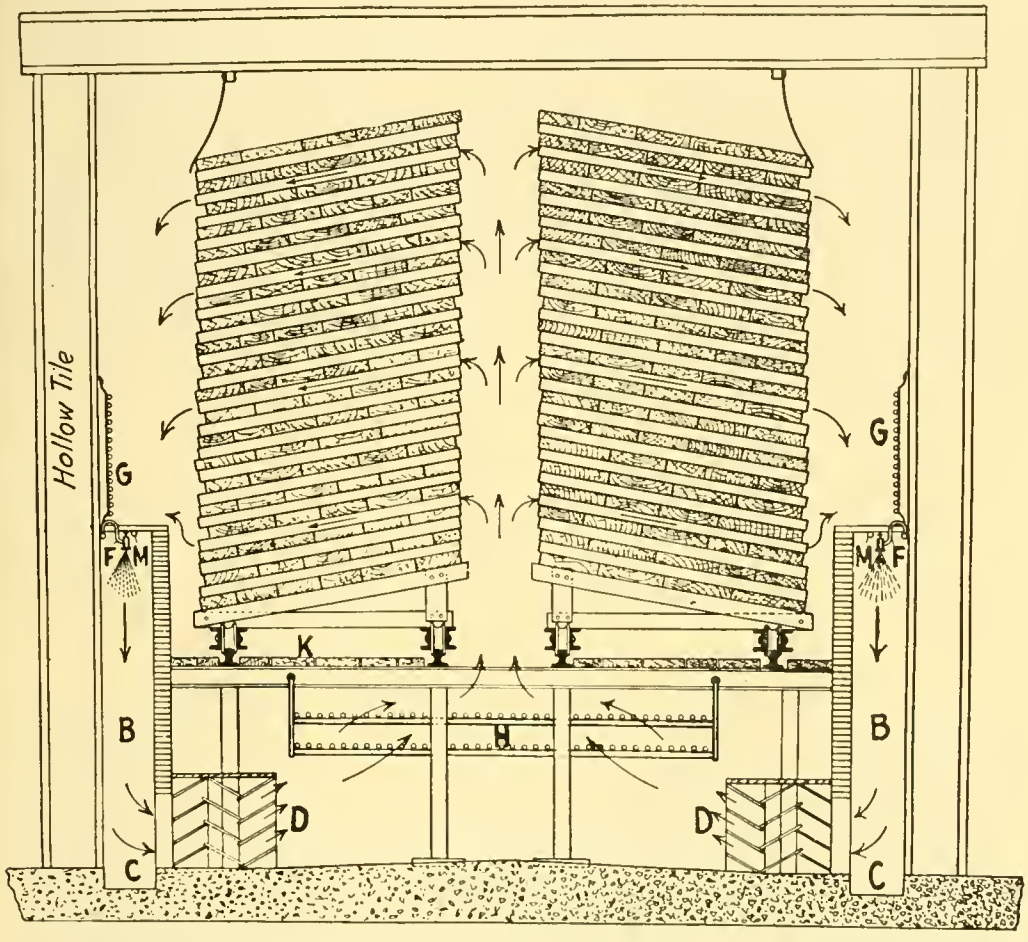

FIG. 85.—Diagrammatic section of humidity-regulated, water-spray dry kiln with inclined piling of lumber. *H*, heating coils; *G*, condensing coils; *F*, water sprays; *B*, spray chambers; *D*, baffle plates; *C*, gutters; *M*, steam spray pipe with holes on lower side. Lumber may also be flat piled. (*From United States Department of Agriculture Bull.* 509.)

Progressive kilns generally are much longer than compartment kilns, some being more than 150 feet in length. Compartment kilns are usually 15 to 50 feet long and 10 to 30 feet wide. Figures 84, 85, and 86 show compartment kilns, and Fig. 87 a progressive kiln.

Compartment kilns are adapted particularly for plants where lumber of different kinds is dried, both with regard to size and

to species and, especially lumber which requires careful regulation of the temperature and humidity. Each kind of lumber can be put into a separate compartment, and there given individual attention. The trucks remain stationary until the lumber is dry,

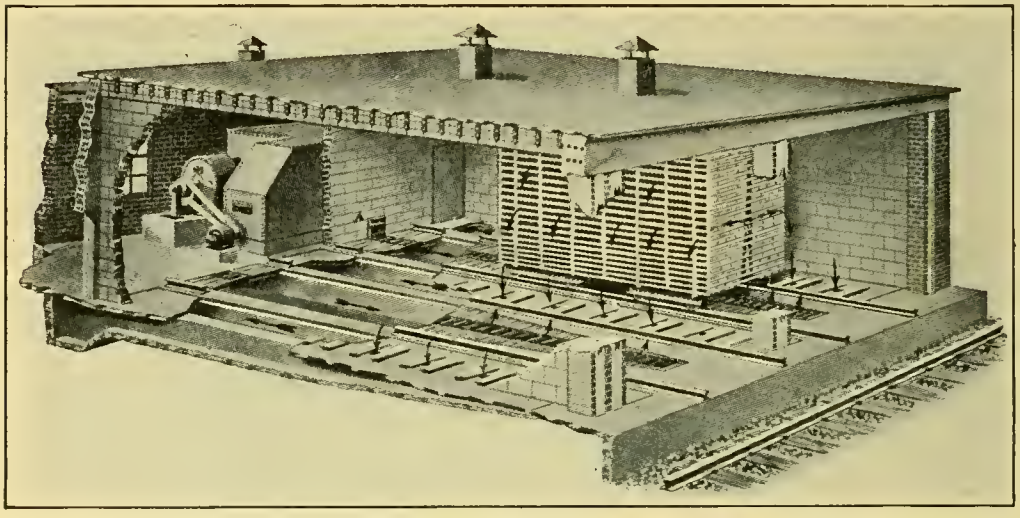

FIG. 86.—Sturtevant compartment blower kiln. (*Courtesy, B. F. Sturtevant Co.*)

so that it is not necessary to disturb the drying conditions by opening the large doors during the drying period, provided there is a small door to afford access to the kiln from time to time to inspect the stock. Furthermore, a compartment kiln can be

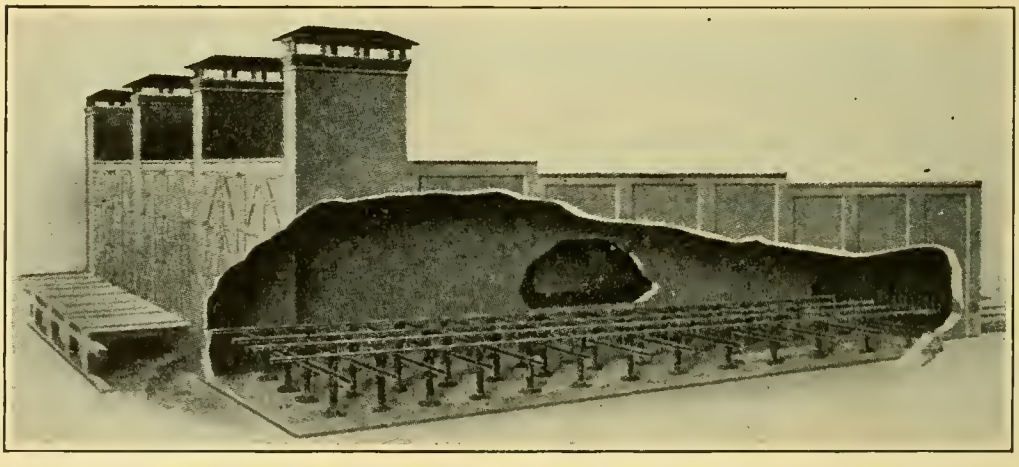

FIG. 87.—Standard progressive kiln. (*Courtesy, Standard Dry Kiln Co.*)

put up on cramped quarters because only one end needs to be opened. As a rule, in a compartment kiln the conditions can be regulated better for each stage of drying than in a progressive kiln.

Progressive kilns are most efficient where easily dried lumber of uniform kind and size is dried continuously, as at saw mills,

planing mills, and factories having a large standard output. These kilns turn out a steady supply of material from day to day, and conditions in the kiln when once standardized need not be changed, so that highly skilled labor is not required for their operation. On the other hand, conditions cannot be regulated so well as in the compartment kiln, and, consequently, the drying is not always so satisfactory. Furthermore, it often happens that thick lumber is put through with thin lumber, heartwood with sapwood, or the species are mixed and improper drying results.

Kilns may be divided into two general types based on the method of heating: (1) The radiator or direct; and (2) the blower or indirect. In the radiator kilns the air is heated in passing through steam coils usually located underneath the trucks of lumber, although they may be along the walls or even within the lumber pile, as in the Nichols kiln. In the blower kilns the air is heated in a chamber outside of the kiln proper by means of steam coils or a furnace, and is forced into the kiln by a large fan.

Kilns may also be classified with respect to the methods of circulating the air as: external circulating, or ventilating; and internal circulating, or recirculating.

By external circulation is meant that fresh air is taken into the kiln from outdoors, heated, passed through the lumber, and then expelled outdoors with the heat and moisture it carries. In recirculating kilns the same air is passed through the lumber piles over and over again; consequently, some means must be provided for taking the excess moisture out of the air. This is done by cold water pipe condensers, water sprays, or canvas curtains on which the moisture is condensed and from which it is evaporated by the air outside of the drying chamber. In some kilns part of the air is recirculated and part is exchanged for fresh air, thereby regulating the humidity.

Ventilating kilns usually are cheaper to construct than recirculating kilns built of the same material because the latter often are provided with condensers to take the excess moisture out of the air. Recirculating kilns have the advantage that they are more independent of outdoor conditions, the same air being used over and over again; therefore, the temperature and humidity can be controlled to better advantage. The more difficult it is to dry the lumber the more important this feature becomes. For drying easily dried lumber, especially if it is first air dried,

a ventilating kiln may be more desirable, while for drying difficult species, especially if still green, better results can usually be obtained with a recirculating kiln. In considering which is cheaper to operate, the following factors must be taken into consideration: heat lost through ventilators; heat lost in heating condensing water;[1] cost of water for condensers; interest on investment; taxes; insurance; repairs; type of man required to operate the kiln; and last, but not least, the amount of degrade produced in the stock.

Ventilating kilns and recirculating kilns may be either of the progressive or of the compartment type, natural circulation or forced draught.

A type known as the "non-draught" kiln is used in the Pacific Northwest for drying Douglas fir and other conifers that can stand a high temperature. In this kiln no ventilators are used, and there is no forced circulation except a slight internal movement of air due to differences in air temperatures. There are no condensers but enough moisture is removed by leakage through cracks and crevices so that the air does not become saturated at the high temperatures maintained, 190 to 230° F. At these temperatures the water is *boiled* off, and the wood dries very rapidly. One-inch green Douglas fir has been satisfactorily dried in this way in from 22 hours to 5 days, depending upon the dryness desired and the temperature maintained.

In the kilns so far discussed air is the principal medium for conveying the heat to the lumber. Another medium, but one less commonly used, is superheated steam. Kilns using superheated steam are comparatively air tight. The air within is replaced by steam usually at atmospheric pressure; but heated above its dew point, that is, above 212° F. Such steam is relatively dry and can take up more moisture and give off some heat before being cooled enough to form condensation.

The chief argument in favor of this method of drying seems to be the mistaken idea that steam is moist heat and will not do so much damage to the lumber as heated air. Superheated steam may be even more damaging to lumber than moist air, because of its high temperature. The real advantage of using superheated steam is that it accomplishes very rapid drying on account of its

[1] Theoretically the heat which passes off with the condensing water should be less than that which escapes through the ventilators. Part of this heat may be recovered by using the condensing water for other purposes.

high temperature. The main objection to its use is that at atmospheric pressure the lumber must be heated above 212° F., in order to keep the steam superheated, which is injurious to many woods. The steam, moreover, must not be superheated a great deal or it will dry the surface of the lumber too fast; therefore, it must pass through the lumber rapidly in order not to become saturated by cooling and by additional evaporation from the lumber.

A high-velocity superheated-steam kiln has been invented by H. D. Tiemann and N. Betts of the United States Forest Service. In this kiln the steam is forced through the lumber piles at a very rapid rate and, therefore, the superheat need not be so great. In this kiln a temperature of 225° F. can be used instead of more than 250° F. as is necessary with kilns of slower steam velocity.

Superheated steam produces the fastest drying, but, unfortunately, can be successfully used on only a few species. One-inch green Douglas fir is being satisfactorily dried by superheated steam in 24 hours.

80. The Heat in a Dry Kiln.—The principal purposes of heat in a dry kiln are, as already stated in Art. **78,** to cause the moisture to come to the surface quickly, and to evaporate the moisture from the surface. Water passes through wood more rapidly when hot than when cold. Since the rate of drying depends upon the speed with which the moisture comes to the surface to be evaporated (it does not depend primarily on the evaporative capacity of the air), the higher the temperature in general the more rapidly the lumber will dry, provided casehardening does not interfere seriously with the transfusion of moisture. In fact the chief reason for maintaining high temperatures in a kiln is to promote the transfusion of moisture, and not to produce evaporation—sufficient evaporation could be obtained by using lower temperatures with lower humidities and a good circulation.

Another important advantage of using high temperatures is that the capacity of the air for moisture increases greatly with the temperature so that the air does not become saturated so easily, and it is not necessary to change it so often, thus adding to the efficiency of the operation. Table XX shows that the moisture-holding capacity of the air increases, for the limits given, from 50 to 100 per cent with every 20 degrees increase in temperature.

TABLE XX.—VARIATIONS IN MOISTURE-HOLDING CAPACITY OF AIR WITH TEMPERATURE

Degrees Fahrenheit	Number of grains of moisture per cubic foot of air when saturated	Degrees Fahrenheit	Number of grains of moisture per cubic foot of air when saturated
20	1.2	120	34.0
40	2.9	140	57.0
60	5.8	160	91.0
80	11.1	180	140.0
100	20.0	200	208.0

Heat is also the sole cause of circulation in all kilns not equipped with mechanical means of producing a movement of air. Sufficiently high temperatures also prevent mold, sap stain, and decay of lumber in a kiln.

The total amount of heat required to dry lumber depends upon many factors, the more important of which are: initial temperature of the lumber; amount of water to be evaporated; heat escaping through ventilators, or heat taken up by the condensing water; losses due to radiation; and final dryness of lumber desired.

In winter, lumber often is frozen when it is put into the kiln so that it becomes necessary to melt several tons of ice in each truck load. The temperature of the air and of the lumber, with contained moisture, must then be raised to the operating temperature, which usually is considerably over 100° F. Besides this a large quantity of heat must continually be supplied to turn the water into vapor. This is known as the latent heat of evaporation, and at ordinary temperatures is about 1,000 British thermal units[1] for every pound of water evaporated. The air must leave the kiln hotter than it entered in order to carry off the evaporated moisture, or, if condensing water is used, it becomes heated and must be replaced by cooler water. Furthermore, as the lumber dries below the fiber-saturation point it takes additional heat to separate the water from the wood on account

[1] A British thermal unit (commonly expressed as B.t.u.) is the amount of heat required to raise the temperature of 1 pound of water 1° F., and is equal to 252 calories.

of the affinity of wood for water.[1] Finally, with increasing dryness it takes longer to remove a given quantity of moisture, so that considerably more heat is required to dry wood to 5 per cent than to dry it to 8 per cent moisture.

The temperatures at which lumber is dried vary greatly in different operations, and range from less than 100° F. to more than 300° F. Few hardwoods can stand a temperature as high as 200° F., although in drying conifers the final temperature often is above 212° F. Greater speed and efficiency are attained by using as high temperatures as the lumber will safely stand. Safe temperatures vary with the species, the dryness of the lumber, and the purpose for which it is to be used. Green maple can endure higher temperature than green oak, and yellow pine than cypress, without deterioration. Woods used for purposes requiring great strength should not be heated over 150° F. for any length of time, while sheathing, flooring, and finish of many species can safely be exposed to higher temperatures when partly dry. Table XXII shows what temperatures may safely be used in connection with certain humidities in drying numerous common species.

81. Humidity.—The method of drying wood in ordinary heated air which is relatively dry is practically obsolete. Warm, dry air dries the surface of lumber too rapidly, causing checking and casehardening. A certain amount of moisture must be maintained in the air of all kilns, the amount varying with the kind of lumber, the temperature of the kiln, and the stage of drying.

The moistness of the air is expressed as its "relative humidity." This is the per cent of moisture in the air based on the maximum amount it can hold at that temperature. For example, at 120° F. the air can hold a maximum of 35 grains of moisture per cubic foot. If only 21 grains are present in each cubic foot of air, the air is three-fifths saturated, or has a relative humidity of 60 per cent. Raising the temperature of air increases its capacity for water, or, in other words, lowers its humidity.[2] For example, 1 cubic foot of saturated air at 110° F. holds about 26 grains of water. If this is heated to 136° F., its moisture-holding capacity

[1] This has been found by F. DUNLAP to range between 20 and 36 B.t.u. per pound of wood substance.

[2] It is common to say that the air has a certain degree of saturation but, in fact, the air has nothing to do with the humidity. It is the *space* that becomes saturated, and it would be just as much saturated by water vapor if the air were not present.

is raised to 52 grains per ccubi foot, and its humidity is lowered to appromately 50 perxi[1] cent. Conversely, lowering the temperature of air reduces its capacity for moisture. If the temperature is lowered to the point where the air becomes saturated, it is said to be at its dew point, and any further lowering of the temperature means that some of its moisture will come out of the air in the form of condensation.

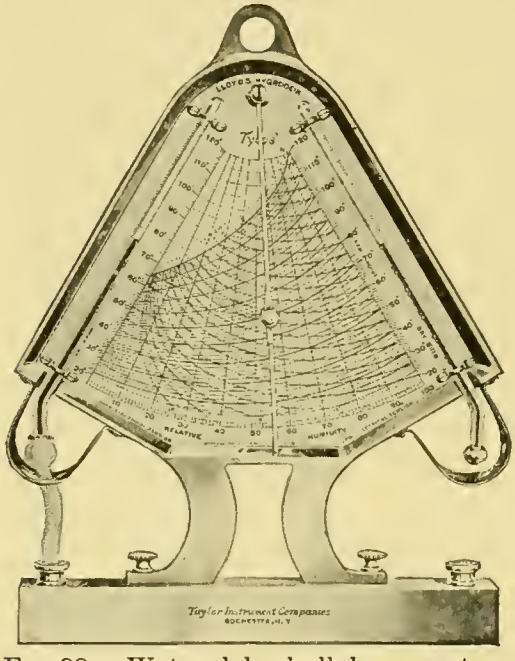

FIG. 88.—Wet and dry bulb hygrometer. (*Courtesy, Taylor Instrument Co.*)

In dry-kiln operation the relative humidity should be comparatively high at first (75 to 80 per cent for green lumber) and gradually lowered after the lumber contains less than 40 per cent moisture, so that at the end of the drying period or at the dry end of a progressive kiln the relative humidity will be 20 to 40 per cent.

The humidity is determined by means of a hygrometer which consists of two thermometers, one with the bulb freely exposed and the other with the bulb surrounded by a piece of cotton or silk kept moist by hanging it in a small vessel of distilled water or pure rain water, as illustrated in Fig. 88. As the moisture evaporates from the fabric around the bulb, it cools the bulb, thereby lowering the reading of the thermometer. The drier the air, the greater is the evaporation, and the greater the difference in the readings of the two thermometers. If the air is fully saturated, no drying will take place and the thermometers will read the same. Table XXI shows the relative humidity for the differences in the readings of the wet and dry bulb thermometers at a barometric pressure of 30 inches of mercury and at varying temperatures.[2] Every dry kiln should be equipped with a good hygrometer, and the operator should consult it freely.

[1] Actually, the humidity would be only 48½ per cent because some of the moisture is lost to the cubic foot on account of expansion.

[2] Prepared from curves similar to those in TIEMANN, H. D., "Principles of Drying Lumber at Atmospheric Pressure, and Humidity Diagram." Forest Service *Bull.* **104**.

Table XXI.—Relative Humidity Table

Difference between Wet and Dry Bulb Thermometers in Degrees Fahrenheit

Temperature of dry bulb	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
60	94	89	83	78	73	68	63	58	53	48	44	39	34	30	
70	95	90	85	81	76	72	68	64	59	56	51	47	43	40	37
80	95	91	87	83	79	75	71	68	64	61	57	54	50	47	44
90	96	92	88	85	81	77	74	71	67	65	61	58	55	52	49
100	96	93	89	86	83	79	76	73	70	68	64	62	59	57	54
102	96	93	89	86	83	80	77	74	71	69	65	62	59	57	54
104	96	93	90	86	83	80	77	74	71	69	65	63	60	58	55
106	96	93	90	87	83	80	77	74	72	69	66	63	60	58	56
108	96	93	90	87	84	81	78	75	72	70	66	64	61	59	56
110	96	93	90	87	84	81	78	75	72	70	67	64	62	60	57
112	96	93	90	87	84	81	78	75	73	70	67	65	62	60	57
114	97	93	90	87	84	81	78	75	73	71	68	65	63	61	58
116	97	93	90	88	84	82	79	76	74	71	68	66	63	61	59
118	97	93	91	88	85	82	79	76	74	71	68	66	64	62	59
120	97	94	91	88	85	82	79	77	74	72	69	66	64	62	60
122	97	94	91	88	85	82	79	77	75	72	69	67	65	63	60
124	97	94	91	88	85	83	80	77	75	72	70	67	65	63	61
126	97	94	91	88	86	83	80	78	75	73	70	68	65	64	61
128	97	94	91	89	86	83	80	78	76	73	71	68	66	64	61
130	97	94	91	89	86	83	80	78	76	73	71	68	66	64	62
132	97	94	92	89	86	83	81	78	76	74	71	69	67	65	62
134	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63
136	97	94	92	89	86	84	81	79	77	74	72	69	67	65	63
138	97	94	92	89	86	84	81	79	77	74	72	70	68	66	63
140	97	94	92	89	87	84	81	79	77	75	72	70	68	66	64
142	97	94	92	89	87	84	82	80	77	75	73	70	68	66	64
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65
146	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65
148	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66
152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67
162	98	95	93	90	88	86	84	82	80	77	75	73	71	69	68
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70
178	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70
182	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70
184	98	96	94	92	89	87	85	83	82	79	77	76	74	72	70
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72

TABLE XXI.—RELATIVE HUMIDITY TABLE—*Continued*

Difference between Wet and Dry Bulb Thermometers in Degrees Fahrenheit

Temperature of dry bulb	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
60															
70	33	29													
80	41	38	35	32	29										
90	47	44	41	39	36	34	31	29	26	25					
100	51	48	46	44	42	39	37	35	33	31	29	27			
102	52	49	47	45	43	40	38	36	34	32	30	28	26	24	
104	52	50	48	46	43	41	39	37	35	33	31	29	27	25	23
106	53	51	48	46	44	42	40	38	36	34	32	30	28	26	24
108	54	51	49	47	45	43	41	39	37	35	33	31	29	28	26
110	55	52	50	48	46	44	41	39	37	36	34	32	30	28	27
112	55	53	51	49	47	44	42	40	38	37	35	33	31	29	28
114	56	53	51	49	47	45	43	41	39	37	35	34	32	30	28
116	56	54	52	50	48	46	44	42	40	38	36	34	33	31	29
118	57	54	53	51	49	46	44	42	41	39	37	35	34	32	30
120	57	55	53	51	49	47	45	43	41	40	38	36	34	33	31
122	58	56	54	52	50	48	46	44	42	40	38	37	35	33	32
124	58	56	54	52	51	48	46	44	43	41	39	37	36	34	33
126	59	57	55	53	51	49	47	45	43	42	40	38	37	35	33
128	59	57	55	53	52	49	47	46	44	42	40	39	37	36	34
130	60	58	56	54	52	50	48	46	44	43	41	40	38	36	35
132	60	58	56	54	53	50	49	47	45	43	42	40	39	37	35
134	61	59	57	55	53	51	49	47	46	44	42	41	39	38	36
136	61	59	57	55	53	51	50	48	46	45	43	41	40	38	37
138	62	60	58	56	54	52	50	48	47	45	43	42	40	39	37
140	62	60	58	56	54	52	51	49	47	46	44	42	41	39	38
142	62	60	58	57	55	53	51	49	48	46	44	43	42	40	39
144	63	61	59	57	55	53	52	50	48	47	45	44	42	41	39
146	63	61	59	57	56	54	52	50	49	47	45	44	43	41	40
148	63	61	60	58	56	54	53	51	49	48	46	45	43	42	40
150	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41
152	64	62	60	59	57	55	53	52	50	48	47	46	44	42	41
154	65	63	61	59	57	56	54	52	50	49	47	46	44	43	42
156	65	63	61	59	58	56	54	53	51	49	48	46	45	43	42
158	65	63	61	60	58	56	55	53	51	50	48	47	45	44	43
160	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43
162	66	64	62	60	59	57	55	54	52	51	49	47	46	45	44
164	66	64	62	61	59	58	56	54	52	51	49	48	47	45	44
166	66	65	63	61	59	58	56	54	53	51	50	48	47	46	44
168	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45
170	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45
172	67	66	64	62	60	59	57	55	54	53	51	50	48	47	46
174	67	66	64	62	61	59	57	56	54	53	51	50	49	47	46
176	68	66	64	63	61	60	58	56	55	53	52	50	49	48	46
178	68	66	64	63	61	60	58	56	55	54	52	51	49	48	47
180	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47
182	68	67	65	63	62	60	59	57	56	54	53	51	50	49	48
184	69	67	65	64	62	61	59	57	56	55	53	52	50	49	48
186	69	67	66	64	62	61	59	58	56	55	53	52	51	49	48
188	69	68	66	64	63	62	59	58	57	55	54	52	51	50	49
190	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49
200	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51

TABLE XXI.—RELATIVE HUMIDITY TABLE—*Continued*

Difference between Wet and Dry Bulb Thermometers in Degrees Fahrenheit

Temperature of dry bulb	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
60															
70															
80															
90															
100															
102															
104	22														
106	23	21	19												
108	24	22	20	19	17										
110	25	23	22	20	18	17	15								
112	26	24	23	21	20	18	17	15	13						
114	27	25	24	22	21	19	18	16	15	13	12				
116	28	26	25	24	22	20	19	17	16	14	13	12	11		
118	29	27	26	24	23	21	20	19	17	15	14	13	12	11	
120	30	28	27	25	24	22	21	19	18	16	15	14	13	12	10
122	30	29	27	26	24	23	22	20	19	17	16	15	14	13	12
124	31	29	28	27	25	24	23	21	20	18	17	16	15	14	13
126	32	30	29	28	26	25	24	22	21	19	18	17	16	15	14
128	33	31	30	28	27	25	24	23	22	20	19	18	17	16	15
130	33	32	30	29	28	26	25	24	22	21	20	19	18	17	15
132	34	32	31	30	29	27	26	24	23	22	21	20	18	17	16
134	35	33	31	31	29	28	26	25	24	23	21	20	18	18	17
136	35	34	32	31	30	28	27	26	25	24	22	21	20	19	18
138	36	35	33	32	31	29	28	27	25	24	23	22	21	20	19
140	36	35	34	33	31	30	28	27	26	25	24	22	21	20	19
142	37	36	34	33	32	30	29	28	27	26	24	23	22	21	20
144	38	36	35	34	32	31	30	29	27	26	25	24	23	22	21
146	38	37	36	35	33	32	30	29	28	27	26	25	24	22	21
148	39	38	36	35	34	32	31	30	29	28	26	25	24	23	22
150	39	38	37	36	34	33	31	30	29	28	27	26	25	24	23
152	40	39	37	36	35	33	32	31	30	29	28	26	25	24	23
154	40	39	38	37	35	34	33	32	30	29	28	27	26	25	24
156	41	40	38	37	36	34	33	32	31	30	29	28	27	25	24
158	41	40	39	38	36	35	34	33	31	30	29	28	27	26	25
160	42	41	39	38	37	35	34	33	32	31	30	29	28	27	25
162	42	41	40	39	37	36	35	34	32	31	30	29	28	27	26
164	43	41	40	39	38	36	35	34	33	32	31	30	29	28	26
166	43	42	41	39	38	37	36	35	33	32	31	30	29	28	27
168	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28
170	44	43	41	40	39	38	37	35	34	33	32	31	30	29	28
172	45	43	42	41	39	38	37	36	35	34	33	32	31	30	28
174	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29
176	45	44	43	42	40	39	38	37	36	35	34	33	32	31	29
178	46	44	43	42	41	39	38	37	36	35	34	33	32	31	30
180	46	45	43	42	41	40	39	38	36	35	35	34	33	31	30
182	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31
184	47	45	44	43	42	41	39	38	37	36	35	34	33	32	31
186	47	46	44	43	42	41	40	39	38	37	36	35	34	33	32
188	47	46	45	44	43	41	40	39	38	37	36	35	34	33	32
190	48	46	45	44	43	42	41	39	38	37	36	35	34	33	32
200	49	48	47	46	45	43	42	41	40	39	38	37	36	35	34

TABLE XXI.—RELATIVE HUMIDITY TABLE—*Continued*

Difference between Wet and Dry Bulb Thermometers in Degrees Fahrenheit

Temperature of dry bulb	46	47	48	49	50	55	60	70
60								
70								
80								
90								
100								
102								
104								
106								
108								
110								
112								
114								
116								
118								
120								
122	10							
124	11	10						
126	12	11	10					
128	13	12	11	10				
130	14	13	12	11	10			
132	15	14	13	12	11			
134	16	15	14	13	12			
136	17	16	15	14	13			
138	18	17	16	15	14			
140	18	17	16	15	14	10		
142	19	18	17	16	15	11		
144	20	19	18	17	16	11		
146	20	19	18	17	17	12		
148	21	20	19	18	17	13		
150	22	21	20	19	18	13		
152	22	21	20	19	19	14	10	
154	23	22	21	20	19	15	11	
156	23	23	22	21	20	15	11	
158	24	23	22	21	20	16	12	
160	24	24	23	22	21	17	13	
162	25	24	23	22	22	17	13	
164	25	25	24	23	22	18	14	
166	26	25	24	23	23	18	14	
168	27	26	25	24	23	19	15	
170	27	26	25	24	24	19	15	
172	27	26	26	25	24	20	16	
174	28	27	26	25	24	20	16	
176	28	27	27	26	25	21	17	10
178	29	28	27	26	25	21	17	11
180	29	28	27	27	26	22	18	11
182	30	29	28	27	26	22	18	12
184	30	29	28	27	27	22	19	12
186	30	30	29	28	27	23	19	13
188	31	30	29	28	27	23	20	13
190	31	30	30	29	28	24	20	14
200	33	32	32	31	30	26	22	16

The humidity is regulated in some kilns by adjusting the ventilation. When the dampers are opened, much fresh air is admitted into the kiln, and, when this is heated, its humidity is lowered. When the dampers are closed, air enters and leaves the kiln slowly, and the air remaining in the kiln becomes laden with moisture and its humidity is increased. Such methods do not always give the best results, however. The circulation should not be cut down too much, but some other method should be used for raising the humidity. One means of doing this is to admit steam into the kiln chamber through one or several perforated pipes. Pans of water are sometimes placed in kilns to raise the humidity, or the hose is turned on the lumber before it is put into the kiln. In some recirculating kilns, the air, after it leaves the lumber, is passed around pipes containing cold water. This cools the air and condenses part of the moisture. The amount to be condensed can be regulated by the temperature of the water in the coils.

In the water-spray kiln invented by Mr. Tiemann of the Forest Service the air is cooled and part of its moisture is removed by passing it through chambers fitted with fine sprays having a temperature lower than that of the air passing through the lumber (Fig. 85).

The advantage of this system is that the temperature of the air as it passes through the sprays can be regulated accurately by the temperature of the spray water, and, since the air leaves the sprays in a saturated condition, its humidity, when again heated and circulated through the lumber, is also regulated by the temperature of the spray water. Furthermore, the sprays are so set that they force the air along and increase the circulation.

82. Circulation.—The proper circulation of air in a kiln is of the utmost importance, because the air carries the heat from the steam coils to the lumber and takes away the moisture. The air must go through the piles as well as around them. Whenever the air does not circulate in the interior of a pile, the lumber remains comparatively cool and damp, causing uneven drying and often mold in "pockets."

The necessity of keeping up the circulation inside the piles of lumber may be illustrated by the following example: Suppose the temperature around the piles is 140° F. and the humidity is 51 per cent. If the air inside of the pile should happen to be as low as 115° F. its humidity would be 100 per cent, or, in other

words, the air would be saturated. In fact the air would probably become saturated at a higher temperature because of the moisture taken from the lumber. Under such conditions no drying could take place inside of the piles, and the inner lumber might even absorb moisture while the outside of the pile was drying rapidly.

In most progressive kilns the circulation is lengthwise. The hot air enters through the floor at the dry end, passes longitudinally through the kiln toward the green end, gradually becoming cooler and of a higher humidity. At the green end it is drawn out by the suction of a chimney or blower. There are some progressive kilns in which the circulation is not longitudinal but vertical-lateral, the gradation of temperature between the two ends being maintained by variations in the amount of heating pipes under the lumber.

In ventilating and blower recirculating compartment kilns the air enters through vents near the floor level or somewhere in the side walls between the floor and the ceiling. It leaves through openings in the ceiling, or in the side walls. Usually the air exits are located near the floor level, because the air which passes through the lumber becomes cooled and naturally will sink along the walls to the floor. It is this moisture-laden air which should be removed and not the hotter, drier air near the ceiling.

In recirculating kilns, without external blowers or other mechanical means of moving the air, the circulation is primarily induced by differences in the temperature of the air in different parts of the kiln, the air rising from the heating coils and falling from the condensers. Such circulation obviously is more sluggish than when tall chimneys or large fans are used to produce a movement of the air. For this reason water jets, steam jets, and small electric fans are sometimes installed to increase the circulation. Whenever this is done, the air should be made to travel in the same direction as it naturally would or there will be a conflict of air currents. A good circulation is especially important in drying green lumber for which the temperature must be comparatively low and the humidity high.

The direction and rate of circulation in a kiln can be determined by watching the smoke from lighted punk sticks with the aid of an electric flash light. To do this properly the kiln must be at the operating temperature and the door closed. The circulation need not be very rapid; a rate of 35 to 75 feet per minute within

the lumber piles is ample except where superheated steam is used.

83. Piling Lumber in a Kiln.—Lumber is piled either crosswise or lengthwise ("end piled") in a kiln (Figs. 89 and 90). It may

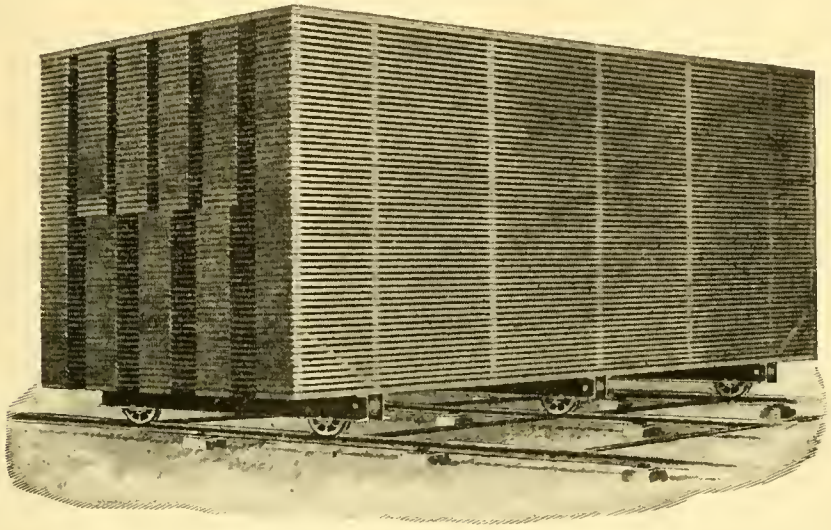

FIG. 89.—Lumber cross piled on kiln trucks. (*Courtesy, Standard Dry Kiln Co.*)

be piled flat, vertically, or in inclined tiers. Kilns requiring longitudinal draught, as most progressive kilns do, are more efficient if the lumber is cross piled, so that the circulation is

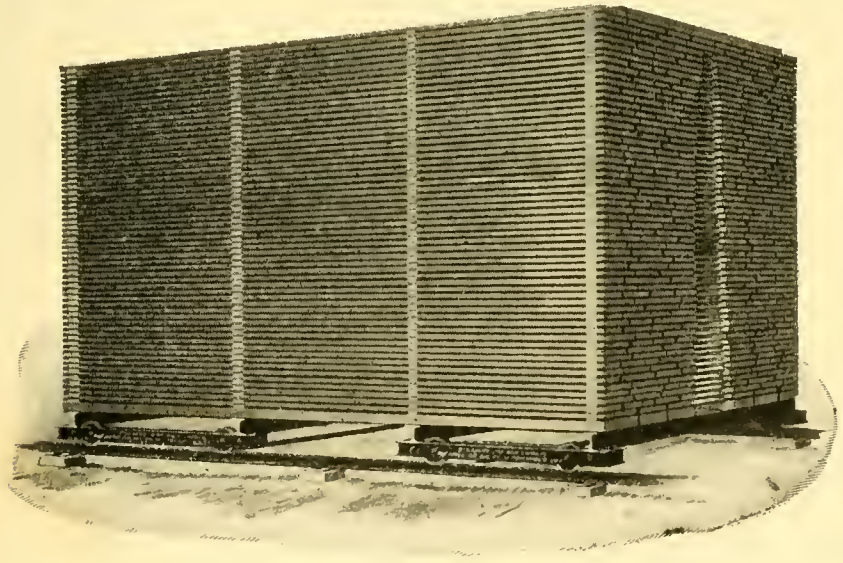

FIG. 90.—Lumber end piled on kiln trucks. (*Courtesy, Standard Dry Kiln Co.*)

parallel to the stickers. End piling is often used in such kilns because different lengths of lumber can be placed on separate trucks and the trucks run close together, thereby saving space.

In most compartment kilns end piling gives better results because the circulation is more or less transverse.

In vertically stacked lumber the boards stand on edge and the stickers, or cross pieces, stand vertically on end, giving the appearance of an entire lumber pile tipped on its side. Figure 91 shows a vertical stacker. No spaces are allowed between the edges of the boards, and in this way the capacity of the kiln is increased. This method of piling is used principally for drying

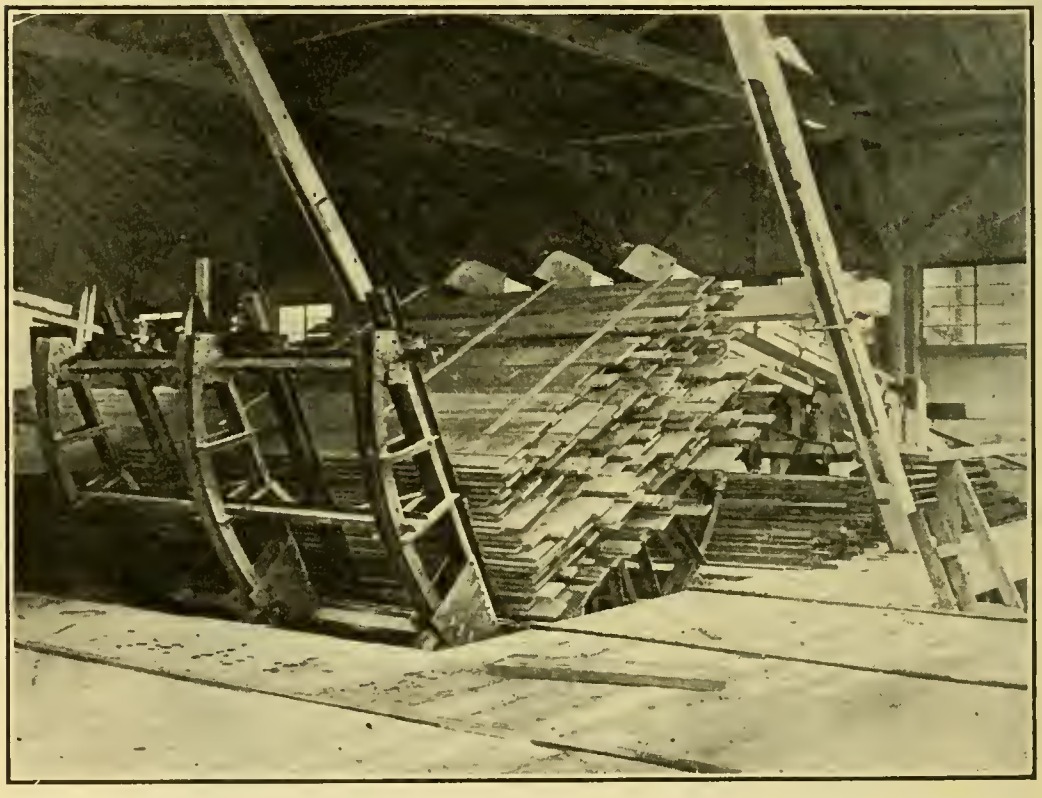

FIG. 91.—Method of piling lumber with vertical stacker. (*Courtesy, Standard Dry Kiln Co.*)

pine and other easily dried conifers. The stacks of lumber are kept tight by some mechanical means or by their tilting sideways as they dry. A new method of piling has been tried with good success by Mr. Tiemann of the Forest Products Laboratory. It consists in piling the lumber at a slant. The hot air enters the higher side of the pile and passes through it in a downward direction, which is the natural way as long as the lumber is cold or the air is cooled through evaporation (Fig. 85). In this method of piling it also is unnecessary to leave spaces between the edges of the boards.

In piling lumber it is advantageous to have both ends of the pile built up square; that is, instead of having the short boards all at one end they are distributed so that both ends are built up straight.

In flat piling a space must be left between the edges of the boards. A good rule is to leave a space of one-fifth of the width of the lumber. In no case, however, should the space be less than ½ inch or over 3 inches.

The cross pieces, or stickers, should be dressed to a uniform thickness of ⅞ or 1 inch for stock up to 2 inches in thickness; and slightly thicker for thicker stock. Half-inch stickers are sometimes used to save space, but this is poor practice. The width of the stickers should not exceed the thickness by more than 1 inch. The stickers should be placed in vertical alignment, the horizontal distance between them being from 2 to 5 feet, the spacing depending upon how easily the lumber warps. The end stickers should be flush with the ends of the pile, in order to keep the ends of the boards from warping. Some operators place the stickers some distance from the ends so as to give the ends more chance to shrink and prevent splitting and to keep the stickers from falling off too easily while stacking and unstacking the lumber. It is doubtful if the advantages so gained offset what is lost in crooked ends.

In wide piles it is desirable to leave a "chimney" about 18 inches wide, in the middle of the pile, extending from the bottom to about two-thirds of the height of the pile. This permits better circulation and more uniform drying.

Whenever possible, lumber should be sorted as to grades, thickness, and kinds so as to give each class of material its proper treatment.

84. Operation of a Dry Kiln.—In starting a kiln run it is desirable to heat the lumber through before any surface drying begins so as to promote the rapid transfusion of moisture from the interior outward. This is done by steaming the lumber. Green lumber should be steamed at 100 per cent humidity from 1 to 3 hours for each 1 inch in thickness at temperatures slightly above that at which drying is to begin. Lumber which has been air dried to below 18 per cent moisture should be steamed at from 65 to 85 per cent humidity instead of at saturation, so that the surface will not absorb too much moisture and cause severe internal stresses, and possibly honeycomb checks. This

conditioning treatment will require from 10 to 30 hours. Steaming air-dried lumber has the additional advantage of softening up the outer layers of each piece, so as to remove any casehardening which may be present, and to make them more permeable to the moisture within. After the steaming treatment, the humidity should be lowered gradually. To obtain 100 per cent humidity quickly it may be necessary to shut off the steam coils wholly or in part and to close the ventilators.

The temperatures and humidities which give the best results depend upon the kind of lumber to be dried, the moisture content, the thickness, and the purpose for which the lumber is to be used. The drying of previously air-dried lumber may begin at higher temperatures and lower humidities than green lumber of the same kind and thickness.

Table XXII gives safe temperatures and humidities for drying 1-inch lumber of the more common kinds. The conditions given in this table apply only if the temperatures and humidities are read in that part of the lumber pile where the air is the hottest and driest. Readings taken near the door or walls may be decidedly different. These conditions are recommended for stock to be used for high-class work, as furniture, cabinets, and interior finish. For box shooks and other rough lumber slightly higher temperatures and lower humidities may safely be used. The same temperatures and humidities may also be used for 5/4- and 6/4-inch stock, but for stock 7/4 to 1 9/4 inch in thickness, temperatures 5 degrees lower should be used. For each additional inch of thickness a further decrease of 5 degrees in temperature should be used. The drying of thoroughly air-seasoned stock can be started at the conditions given for 25 per cent moisture. When it is necessary to dry at one time in a kiln two or more kinds of lumber requiring different drying schedules, the mildest of the schedules required should be followed.

Throughout the drying process the temperatures and humidities should be read carefully in that part of the kiln where the air is the hottest and driest, and the readings recorded. The lumber should be watched carefully and tests made occasionally, since good drying does not always result from merely following a schedule. In drying green lumber at temperatures below 135° F., mold may form on the lumber and prevent its drying. This mold may be killed by steaming the lumber for ½ to 1 hour at

TABLE XXII.—SAFE TEMPERATURES AND HUMIDITIES FOR DRYING 1-INCH, GREEN LUMBER

Species	At beginning of drying period	At 25 per cent moisture	At end of drying period
Yellow pine, Douglas fir, hemlock, spruce, and cedars.[a]	180° F. 85%	185° F. 60%	200° F. 30%
Cypress, larch, redwood,[a] white pine, and sugar pine.	160° F. 85%	170° F. 60%	180° F. 30%
Basswood, birch, and yellow poplar...	140° F. 80%	155° F. 60%	170° F. 20%
Ash, butternut, chestnut, cottonwood, elm, red gum, and willow.	135° F. 80%	150° F. 60%	165° F 20%
Beech, black gum, maple, and tupelo gum.....	130° F. 80%	145° F. 60%	160° F. 25%
Holly, hornbeam, magnolia, and mahogany.	125° F. 80%	140° F. 60%	155° F. 25%
Cherry, hickory, locust, persimmon, and sycamore.	120° F. 80%	135° F. 65%	150° F. 30%
Northern highland oak.....	115° F. 80%	130° F. 65%	145° F. 30%
Northern lowland and southern highland oak.	110° F. 85%	125° F. 65%	140° F. 35%
Southern lowland oak.....	105° F. 85%	120° F. 70%	135° F. 40%

[a] For drying very wet redwood and western red cedar a temperature of 135° F. should be used till the wood is dried to 40 per cent moisture, when it may be raised gradually to the final temperature given for these species in the table.

165° F. Particular care must be taken to have the humidity 100 per cent while steaming or the lumber may check badly. After all steaming periods the humidity must be lowered gradually.

If severe checking begins to take place during drying, the humidity should be raised sufficiently to stop further checking. Tests for casehardening should be made from time to time. This is done by cutting an inch section across the grain, at least 1 foot from the end of the board; resawing this into three or more prongs; and breaking out every other one leaving the outer two as indicated in Fig. 92. If the prongs curve in immediately upon sawing, it indicates that the surface is in a set condition.[1] If the tendency to curve in is very strong, as in Fig. 92*A*, the lumber should be steamed so as to soften up the outer surface and relieve the set condition on redrying. Steaming to relieve

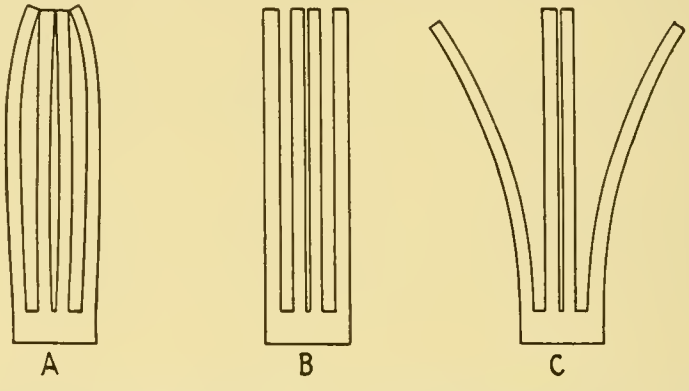

FIG. 92.—Method of cutting samples for case-hardening test. *A*, casehardened; *B*, free from stress; *C*, stresses reversed.

casehardening during the run should be done at from 160 to 180° F., using 100 per cent humidity for from ½ to 3 hours. If honeycombing takes place, it means that the surface is badly casehardened, and the lumber should be steamed at once. During a kiln run frequent moisture determinations should be made of the stock in different parts of the kiln as described in Art. **20** to see how the drying is progressing.

At the end of the run, tests should also be made for casehardening. In this case the section should be allowed to become thoroughly dry in a warm room before cutting it into prongs, thus representing the condition in which the stock is to be used. If the prongs of the room-dried, resawed section have a strong

[1] In the early stage of drying, the resawed section may curve outward as illustrated in Fig. 34*A*. This means that the surface is much drier than the interior. If the curvature is great, the humidity should be raised the same as for checking until the center has become considerably drier.

The prongs may turn in if a test is made immediately after prolonged steaming of air-dry lumber, because the moisture absorbed by the surface causes it to swell.

tendency to curve in, the lumber should be steamed for a period of ½ to 5 hours at a temperature not to exceed 10 degrees above the final operating temperature. Care must be taken not to over-steam the stock or the stresses will be reversed at least in the outer layers as shown in Fig. 92*C*. There is less danger of over-steaming if the steaming is done when the stock still contains several per cent moisture above the final dryness desired, or if 60 to 85 per cent humidity is used, instead of saturation, for a period of 10 to 30 hours.

Before the stock is removed from the kiln it should also be tested for moisture content as described in Art. **20,** to see if it is dry enough.

85. Time Required for Kiln Drying Lumber.—The time required for drying lumber in a kiln varies from 24 hours to 4 or 5 months. One-inch lumber of yellow pine, Douglas fir, western hemlock, and most other softwoods dried to reduce the shipping weight is dried from 48 to 96 hours, high temperatures being used. Douglas fir has been dried in 24 hours in a blower kiln at a temperature of 300° F., but such speed involves considerable risk and is rarely practiced. Douglas fir and other softwoods have been dried in 24 hours in the high-velocity, low-superheat kiln described in Art. **79** with practically no loss whatever.

Green oak requires about one month for every inch of thickness. One-inch green black walnut requires about 20 days, red gum 18 days, mahogany and maple 15 to 17 days, birch 18 days, basswood 9 days, cypress 10 days, and yellow pine and Douglas fir 4 to 6 days. These periods refer to drying the lumber to 5 per cent moisture and for exacting purposes, as high-class furniture, cabinets, etc. For ordinary rough construction the time may be reduced somewhat. Air-dried lumber (at 25 per cent moisture) takes a little over half the time required for green lumber.

86. Dryness Attained.—Very little information is available as to the amount of moisture remaining in the lumber after it is kiln dried; in fact, few operators know how dry their lumber is when it is taken from the kiln. The inspection is usually based on such haphazard methods as lifting a board and judging by its weight, or whittling the lumber, or running a piece through the planer to see how it "works." If the shavings come off short and brittle, the wood is too dry; and if the shavings tend to remain in long shreds, it is too wet. It is safe to say that opera-

tors, as a rule, do not dry their stock enough rather than too much. Insufficiently dried lumber, with its subsequent shrinkage, is one of the chief factors in prejudicing builders and manufacturers against the use of wood.

Lumber to be used for furniture, cabinets, etc., in the interior of heated buildings, should be dried to from 4 to 6 per cent moisture; interior finish and flooring to from 5 to 8 per cent; parts of vehicles and airplanes which must remain tight under the driest atmospheric conditions to from 7 to 9 per cent. For the arid southwestern portion of the country, vehicle and airplane stock should contain from 2 to 4 per cent less moisture, and for parts of the country where the humidity is high it should contain from 2 to 4 per cent more. If the lumber is dried only to reduce the shipping weight or for outdoor work, which does not require tight joints, it need not be dried below 12 to 15 per cent moisture, since such lumber is usually stored in open sheds and will absorb moisture from the atmosphere until it contains almost as much as thoroughly air-dried wood.

CHAPTER IX

DETERIORATION OF WOOD

Wood is subject to several forms of deterioration. Decay is the most common and most damaging in the aggregate. Fire destroys immense quantities of lumber each year. Insects riddle stored lumber or manufactured wooden articles with their galleries, often continuing their damaging work entirely unsuspected until the material is unfit for further use. Marine borers attack wharf timbers, piling, wooden ships, and other wooden structures in salt water in temperate and tropical climates, and perforate the wood so as to weaken it seriously, often in a short time. Mechanical wear and even weathering have their depreciating effects, frequently making replacement necessary before decay sets in. Stains and discolorations depreciate a large amount of high-grade lumber each year.

The losses caused by these deteriorating influences are enormous and run into many millions of dollars each year. It is estimated that 9 billion board feet of timber products are destroyed each year by decay alone. The total yearly fire loss in the United States not including standing timber and sums expended for maintaining insurance companies, fire departments, and other protective measures amounts to about $275,000,000. The damage done by insects to forests and forest products is estimated at $130,000,000 annually. The damage done by marine borers to wharf timbers and piling in one locality, namely, the lower courses of the Sacramento and San Joaquin Rivers from Antioch to San Pablo Bay, Cal. amounted in terms of replacement and repair in the 2 years preceding June, 1920 to $15,000,000. This is an unusual case, and the yearly loss in any locality may never be so great again if proper precautions are taken. However, the attack by marine borers of wharves and wooden ships will always be a serious menace.

87. Decay.—Decay, rot, or dote in wood is the destruction of the cell walls by certain low forms of plants known as *fungi*.[1]

[1] Bacteria often are mentioned as producing decay, but their ability to attack sound wood is negligible.

The fungi consist mostly of microscopic threads, each of which is known as a *hypha*. Collectively they form a *mycelium*. The hyphae traverse the wood in all directions dissolving out of the cell walls materials which they use for their own growth. Figure 93 shows fungous hyphae in wood magnified 250 diameters. Frequently the mycelium also develops on the surface, especially on pieces of damp decaying lumber, where it appears in the form of white, stringy, or leathery masses. After the fungous myce-

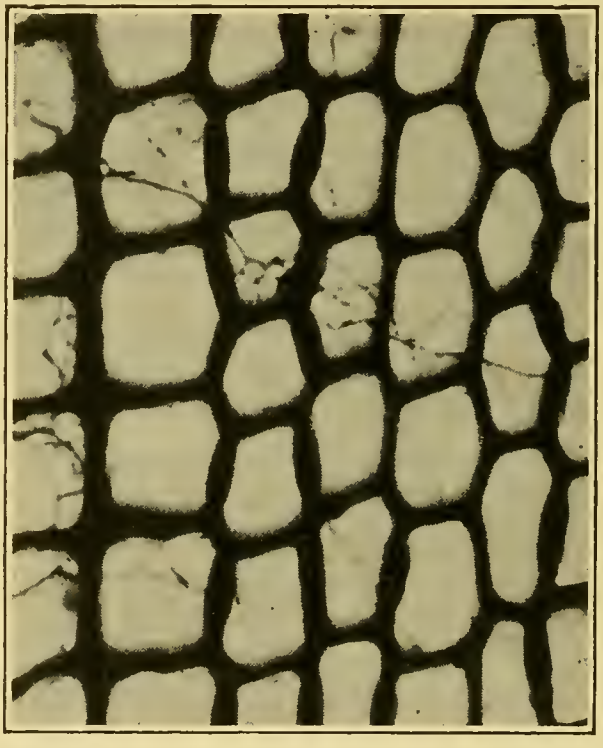

FIG. 93.—Cross-section of Douglas fir showing fine threads, or hyphae, of wood-destroying fungus within the cells. Magnified 250 diameters. (*Courtesy Forest Products Laboratory.*)

lium has developed considerably within the wood and other conditions are favorable, it produces on the surface of the infected wood a fruiting body having the shape of a bracket, horse's hoof, toadstool, or compact surface covering. Figure 94 shows the fruiting body of a common wood destroying fungus. These fruiting bodies produce millions of microscopic *spores*, which are similar in function to the seeds of higher plants. The spores, being as fine as dust, are blown about by the wind; and when they settle on damp surfaces or in checks in moist wood, they germinate and start their destructive work.

Fungi, by means of their hyphae, may also spread from one timber to another in contact with it, without the formation of spores. In this way rot can spread in concealed portions of a building without being suspected. Herein lies one of the chief dangers of decay, for it may be far advanced before its presence is discovered.

There are many species of fungi, but only certain ones attack wood. Of these only a limited number attack living trees. The others confine their destruction to cut timber. Some of the

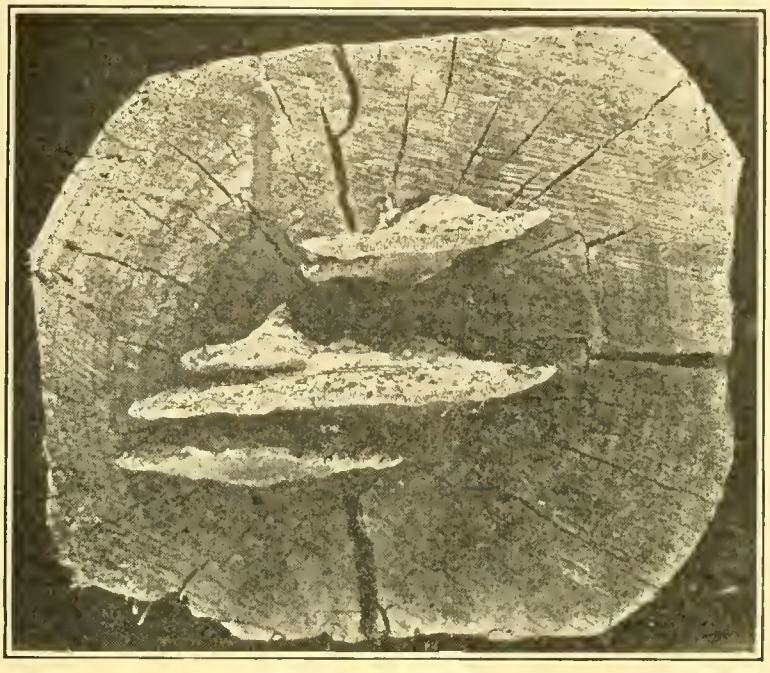

Fig. 94.—Fungus (*Daedalea confragosa* (Bolt.) Fr.) fruiting body growing from end of decaying tie. (*Courtesy, C. J. Humphrey.*)

fungi which occur in living trees do not make much headway after the trees are cut. A good example of this occurs in pecky cypress, which is cypress containing numerous holes or pockets produced by rot in the standing tree. Since pecky cypress is practically as durable as sound cypress it can be used to advantage, because of its lower price, for barn floors, greenhouses, and other purposes where great strength is not essential but resistance to decay is important.

88. Conditions Necessary for Decay.—Four conditions are necessary for the development of fungi: warmth, air, moisture, and wholesome food.

Fungi, like other plants, require a certain amount of warmth for their best development. In cool weather, growth is retarded,

and at low temperatures the fungus becomes dormant, but the most severe cold will not kill the spores or mycelium. However, fungi cannot endure temperatures much above the optimum for their best development. A rise of from 4 to 8 degrees above the optimum will cause growth to cease, and even death may ensue as in the case of the dry-rot fungus (*Merulius lachrymans*) which is very sensitive to heat.[1] Of a series of some fifty species of fungi tested at the Forest Products Laboratory by C. J. Humphrey none would grow above 108° F. However, this does not mean that all would be quickly killed at this temperature. It is very probable that the prolonged high temperatures usually maintained in a dry kiln completely destroy any fungi that may be in lumber which is being kiln dried. Tests made by Hubert[2] on stock up to 4 inches thick, of six different kinds of wood, kiln dried for 16 days at temperatures ranging from 120 to 135° F. and humidities from 70 to 100 per cent, showed that of six species of fungi alive in the wood before drying none was alive after kiln drying. He further found that steaming stock 4 inches thick at 100 per cent humidity and a temperature of 120° F. for 24 hours, or 145° F. for 3 hours, killed all the fungi in the wood tested. This, however, does not make the lumber immune from fresh attack under favorable conditions.

Fungi, like other living organisms, require air for growth. Wood from which air is entirely excluded, as water-logged pieces, will last indefinitely. Fence posts and telephone poles set in wet soil or clay will not rot several feet beneath the surface so quickly as those set in well-drained soil, especially sandy soil, because the former conditions retard the access of air to the portions underground.

At a railroad cut in northern Wisconsin pieces of spruce wood were found 50 feet below the surface. This wood, according to geologists, had been deposited there by a glacier some 500,000 years ago, but it showed no evidence of serious decay although it was badly crushed. The absence of sufficient air probably was responsible for its preservation.

The interior of trees and timbers usually contains enough air in the cells so that fungi can live and grow. The reason the

[1] Humphrey, C. J., "Timber Storage Conditions in the Eastern and Southern States with Reference to Decay Problems." United States Department of Agriculture *Bull.* **510.**

[2] Hubert, E. E., "The Effect of Kiln Drying, Steaming, and Air Seasoning on Certain Fungi in Wood." United States Department of Agriculture *Bull.* **1262.**

heartwood of living trees often is infected with decay while the sapwood is sound is that the heartwood contains sufficient air while in the sapwood the cells are filled almost entirely with water and contain insufficient air for fungous growth. Logs floating or submerged in water are practically immune from decay because the water in and about the logs prevents the access of the necessary air.

Moisture is absolutely necessary for decay. Damp wood usually decays rapidly whereas dry wood, such as furniture in a dwelling, will not rot. Sound wood has been found in some of the dry tombs of Egypt where it has been for thousands of years. As a rule wood must contain over 20 per cent moisture before it will decay, although this varies with different fungi. The form of decay known as "dry rot" is caused by a fungus which is popularly believed to be able to get along on less moisture. It, however, needs moisture as well as any other fungus, but it has the power to produce moisture or to transport it to the place where the decay takes place.

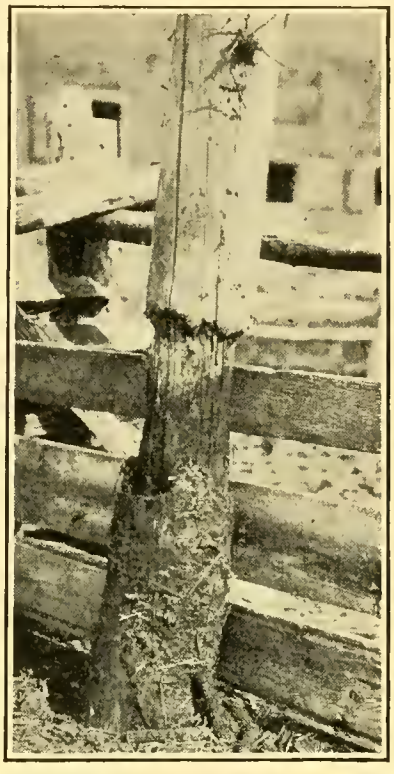

FIG. 95.—Fence post removed from ground, showing most decay at ground line where conditions for decay are most favorable. (*Courtesy, Forest Products Laboratory.*)

Usually the greater part of buildings is immune from attack by fungi on account of lack of moisture. Only those parts decay where moisture collects and cannot readily evaporate. The bottom of porch posts, sills on or near the ground, ends of timbers encased by masonry, places which catch the drips from sinks or leaky roofs, or woods surrounding water pipes that "sweat" are the locations where decay takes place first, as a rule.

In the manufacture of certain kinds of paper and in cotton weaving, a warm, humid atmosphere is necessary. The timbers of buildings in which such a condition exists are quite susceptible to decay, especially in the roof where condensation often takes place. In certain cases it has been necessary to remove such timbers after less than 5 years of service.

A good example of the influence of moisture on decay is that of the thick staves of water tanks, which may decay in the middle between the two surfaces but remain sound at the surfaces, the side next to the water being too wet, and on the outside being too dry for decay to take place. Fence posts usually decay at the ground line first for there the conditions of warmth, air supply,

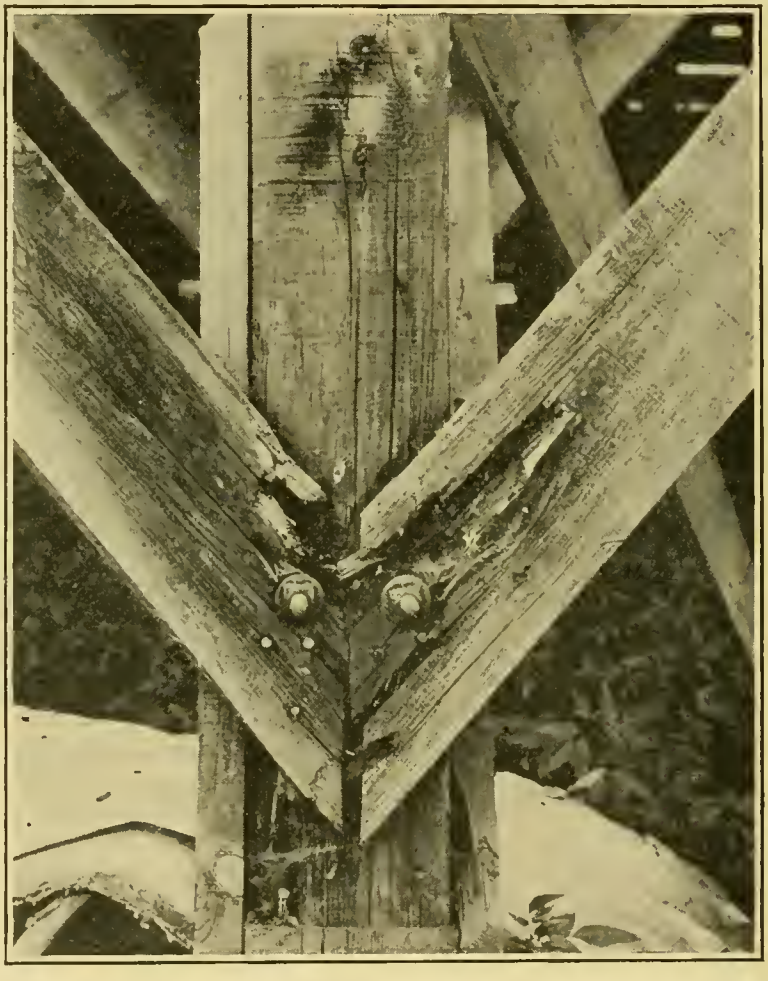

FIG. 96.—Decay of braces at joint where moisture has collected. (*From United States Department of Agriculture Farmer's Bull.* 744, "*The Preservative Treatment of Farm Timbers.*")

and moisture are most favorable. Figure 95 shows decay in a fence post, and Fig. 96 shows decay in a structure above ground.

The importance of not enclosing portions of timbers on all sides, especially with masonry, and of keeping wood dry by allowing the circulation of fairly dry air around it as much as possible is too often not understood, or at least not considered.

The food of a wood-destroying fungus is principally the cell wall, which is made of cellulose infiltrated with lignin and other materials, as already explained in Chap. VI. Some fungi prefer

the lignin, leaving the cellulose as a white mass; others attack the cellulose, leaving the other substances in the form of a brownish brittle mass; while still others destroy the entire wood fiber. A microscopic examination of partly decayed wood shows that the cell walls are thinner than normal and that the hyphae have bored through the walls in many places. The destruction of the wood by fungi is caused by a secretion known as a ferment or enzyme, which has the power of dissolving the cell wall, forming compounds which can be absorbed by the fungus and used for its further development.

89. The Natural Durability of Wood.—It is well known that there is great variation in the resistance to decay of different species of timber. Locust and cedar are very durable, while basswood and balsam rot quickly under conditions favorable for decay. Of the same species, some timbers last longer than others under apparently the same conditions. In the same tree the heartwood usually is more resistant to decay than the sapwood, although in aspen, maple, balsam, spruce, and a few others there is little difference in the durability of heartwood and sapwood. The relative durability of common woods is given in Table XXIII. This table is based on the average life of heartwood timbers under conditions favorable for decay. Variations may occur; for example, an individual piece of white oak may last longer than a piece of cedar under the same conditions. On the other hand apparent differences in durability often are due to differences in the conditions under which the wood is placed.

In no species is the untreated sapwood durable in damp locations. The greater durability of the heartwood is ascribed to certain gums, resins, tannins, and possibly other materials which become infiltrated into the cell walls and are offensive to the fungus. These substances discolor the heartwood making it darker. It is a well-known fact that the very dark woods such as locust, black walnut, ebony, redwood, and black cherry are more durable than light-colored woods, such as maple, beech, birch, and hemlock. Some light-colored cedars, on the other hand, are very resistant to decay. Their durability probably is due to certain oils found in the heartwood. Experiments have shown that if the heartwood of oak is leached in hot water, it becomes less resistant to decay and the extract is toxic to wood-destroying fungi.

The statement is often made that the rapid decay of sapwood is due to the sugars, starches, and albuminous matter contained

TABLE XXIII.—RELATIVE DURABILITY OF THE HEARTWOOD OF COMMON WOODS

Conifers	*Hardwoods*
Very durable	
Cedar, northern white	Catalpa
Port Orford	Chestnut
Red (pencil cedar)	Locust, black
Western red	Mulberry
Cypress	Osage orange
Redwood	Walnut, black
Durable	
Fir, Douglas	Cherry, black
Larch, eastern (tamarack)	Locust, honey
Western	Oaks, white
Pine, longleaf	
Eastern white	
Intermediate	
Pine, loblolly	Ash, white
Norway	Butternut
Shortleaf	Elm, red
Sugar	White
Western white	Gum, red
	Oaks, red
	Poplar, yellow
Non-durable	
Firs, true	Aspen
Hemlock, eastern	Basswood
Western	Beech
Pine, western yellow	Birch
Spruces	Box elder
	Buckeye
	Cottonwood
	Hickory
	Maple, hard
	Soft
	Sycamore
	Tupelo
	Willow

in it, and that the heartwood is more immune to attack by fungi because it does not contain these substances. From this it would be inferred that the sugars, etc. act as a bait to attract the fungi which, after they get into the wood, attack the cell walls also. Judging from the readiness with which the heartwood of some species decays under certain conditions it does not seem reasonable that the fungi require any special inducement to begin their attack on wood, the cell walls being very wholesome food for them.

The statement even has been made that since the sugars and starches in a living tree are almost all used up in the spring, wood cut early in the growing season is less liable to decay than that cut at any other time of the year. This is not borne out by experience, however, since it is well known that trees cut in spring may decay appreciably before the end of summer if left in damp places. In fact, the opposite claim is also made, namely, that timber cut in spring and summer when the sap is said to be "up" is more subject to decay than timber cut in fall and winter when the sap is said to be "down." The reason for this belief is that trees felled in spring and summer are subject to immediate attack by fungi because the wood is moist and the temperature is favorable. Winter-felled timber, on the other hand, usually dries out sufficiently at the surface by the time warm weather comes so that fungi do not find conditions very favorable for attacking the wood. However, if the interior of the wood remains moist, decay enters sooner or later. Therefore, the difference in the durability of wood cut at different seasons could at most be only a few months. The care the wood receives *after* it is cut is what counts toward its durability.

The proportion of sapwood often plays an important role in the durability ascribed to different species. In woods with narrow sapwood the entire decay of the sapwood may not make the timber unfit for use. But if the sapwood is wide, its decay will leave only a small and insufficient core of heartwood. In such a case, the usefulness of the timber would be governed by the life of the sapwood.

The influence of resin, or pitch, on the durability of pines or other resinous woods has been the subject of considerable discussion. It is well known that resinous pine knots will be sound long after the rest of the tree trunk has decayed in the forest. On the other hand, laboratory experiments with fungi

growing on highly resinous media show that rosin is not poisonous to fungi. It seems to be the volatile oils, which in the southern yellow pines are turpentine and pine oil, that have a toxic effect on fungi. In the course of time these oils volatilize, and eventually resinous wood decays.

The hardness of wood bears no relation to the comparative resistance to decay of different species. Some dense woods decay more rapidly than other of similar density. For example, maple and hickory decay much more readily than white oak and black locust. Also among the softer woods very durable and non-durable woods are found. In the same species the heavier pieces will not be weakened to the same extent as the lighter pieces when both are exposed to decay under the same conditions for the same length of time, although both may lose equally in weight.

Woods with abundant tyloses[1] in the pores, for example, white oak, black locust, osage orange, and mulberry, are more durable in general than many other species in which the tyloses are sparingly developed. However, this does not always hold true, and the above cases may be due to a coincidence rather than a direct relation between tyloses and durability. There is no reason to believe that tyloses are more of a mechanical hindrance to the entrance of fungi into the wood than other cell walls. It might seem possible that they prevent the rapid spread of fungi in wood by closing up the pores, but in soft woods like balsam fir where there are no pores, and the fungus can spread only by going through cell wall after cell wall, decay often is very rapid.

There seems to be a general opinion among lumbermen that "dead" timber, that is, timber which died on the stump, is not so durable as "live" timber. If the tree is utilized soon after it has died on the stump, there is no reason why the wood should not be so durable as that from a tree killed by the woodsman's axe; but if the tree has remained standing for several years after death, the sapwood, and even the heartwood, may have become infected with decay which will continue until the timber is thoroughly seasoned. In considering this subject it may be well to remember that the heartwood of "live" trees is entirely dead, and in the sapwood only a comparatively few cells are living. The question should be "Is the timber sound?" and not "Was the tree dead when cut?"

[1] For meaning of "tyloses" see Art. 4.

Railroad men have for many years considered hewed ties more durable than sawed ties on the assumption that the rain runs off the smooth surface of a hewed tie more readily, and, therefore, it was believed the tie would not absorb so much water. However, of late there is less discrimination between hewed and sawed ties, because records of the life of ties do not show any decided advantage in favor of hewed ties.

90. Sap Stain.—Sap stain, or blue stain, is a bluish discoloration of the sapwood. It is common in the pines, spruces, red gum, hackberry, and some other species. Sap stain, like decay, is due to fungi which germinate and develop from spores on moist surfaces of the wood. In this case the thread-like filaments which enter the wood are dark in color, giving it a bluish appearance, although the cell walls of the wood are not discolored. The sap stain fungi live chiefly on the sap in the wood and do not attack the cell walls to any serious extent although they make small holes through them so as to be able to pass from one cell into the next. As soon as the sap in the wood dries up, the fungi become inactive. Early removal of felled timber from the forest, transportation of unseasoned lumber in ventilated cars, and rapid seasoning are effective methods of reducing blue stain. The fungi responsible for sap stain do not weaken the wood appreciably, but the discoloration unfits it for interior trim and many other uses where it receives a natural finish.

A warm humid climate is especially favorable for the development of sap stain. Under certain conditions it may discolor lumber in from 24 to 48 hours. It is more prevalent in the South than in the North, and does not occur in cold weather.

One of the most effective methods of preventing sap stain is to put the logs in the water soon after they are cut, and the lumber directly into the dry kiln green from the saw. This method is expensive, however, and cannot be practiced at mills where log ponds and dry kilns are not used.

Another method of preventing, or at least reducing, sap stain is to dip the sap lumber in a chemical solution which is poisonous to fungi. By preventing the growth of fungi on the lumber while it is green it can be air dried in open piles without severe staining, except in warm rainy weather when this remedy is only partly effective. At some of the larger softwood mills the sap lumber on its way from the saw to the yard is passed through a vat containing a toxic solution. Sodium carbonate (soda ash) and sodium

bicarbonate (baking soda) are the chemicals most commonly used for this purpose. The most efficient results are obtained with about a 11 per cent solution of carbonate of soda in wet weather and a 5 to 6 per cent solution in dry weather, or, if the bicarbonate is used, an 8 per cent solution in humid weather and a 4 per cent solution in dry weather. Sodium fluoride has been tried as a preventive for sap stain. At times it has given satisfactory results, but under severe conditions it was not sufficiently effective.

The dipping of lumber in either of the carbonate of soda solutions has a fireproofing effect. Shavings from dipped lumber do not burn so readily as from undipped material, but the difference is slight. Solutions of the carbonates of soda give the surface a brownish discoloration, but sodium fluoride leaves the wood white.

Although sap stain does not destroy lumber like decay, it must be remembered that the condition favorable for sap stain—namely, green lumber in a warm humid atmosphere—also is favorable for decay. Therefore, sap-stained material may also contain wood-rotting fungi, but this is not necessarily the case.

91. Molds.—Molds of the nature of those which form on damp bread or cheese may form on lumber. They also are fungi but are confined mostly to the surface (they penetrate the cells only slightly) and usually can be dressed off. Molds develop only on lumber which is stored so that little or no drying takes place. They usually grow more profusely on the sapwood than on the heartwood.

From a commercial standpoint, molds do not appreciably affect the strength of wood. Molds are objectionable primarily because of the surface discolorations which they produce and because they often are considered as a kind of agent of decay by those not familiar with their habits. While molds should not be classed as decay-producing fungi, it should be remembered that the conditions favorable for the growth of molds are also favorable for wood-rotting fungi. Woods which have been moldy for some time, therefore, may also be infected with decay.

Molds sometimes form in great masses on green lumber which is being kiln dried at low temperatures (below 135° F.) and high humidities. In such cases they are particularly annoying because they interfere with the drying.

One of the most practical methods of preventing the growth of mold on unseasoned wood is to pile it during storage and during transportation so that it is well ventilated. In a dry kiln the superficial growth of mold can be destroyed by steaming the stock at 170° F. and 100 per cent humidity for 1 hour.

92. Chemical Stains.—California sugar pine is subject to a brownish discoloration especially pronounced near the junction of the heartwood and sapwood. This brown stain is produced most abundantly in green wood exposed to hot humid weather. The exact cause of this stain is still unknown. It is not due to a fungus but appears to be a chemical stain brought about by changes in the composition of the materials infiltrated in the cell walls. Like the blue sap stain it has no effect on the wood except to detract from its appearance.

Western yellow pine sapwood is subject to a brownish stain which penetrates only slightly but often far enough so that it will not dress off. This stain is most common in kiln-dried lumber sawed from logs which have been lying about for several months after cutting.

Some kinds of wood, especially alder, stain soon after they are cut and exposed to the air. Such stains are produced by an enzyme which can be destroyed and the staining prevented by soaking the freshly cut wood for a short time in boiling water.

Maple sapwood is subject to a reddish brown discoloration in both air seasoning and kiln drying. Rapid seasoning outdoors or low temperatures (120 to 160° F.) and low humidities (60 per cent at start to 25 per cent at finish) in kiln drying reduce this stain to a minimum. It is claimed that by drying maple lumber stacked on end, as in Fig. 76, the stain is reduced to a minimum.

Basswood lumber sawed and seasoned in summer turns pale brown, while that which is cut and partly seasoned in winter remains white.

When green oak comes in contact with iron it turns a bluish color on account of the reaction between the tannin and the metal the color often penetrating to a considerable extent.

93. Insects.—The damage done by insects to standing timber, lumber, and manufactured wooden products is far greater than is generally recognized. Most of this damage is done by the

insects in the larval stage[1] (Fig. 97), but some of the damage is done by adults in eating their way out of the wood after metamorphosis. Ambrosia beetles and ants are an exception in that the adults penetrate far into the wood, excavating galleries for the development of their young.

(*a*) *Attack on Standing Timber.*—Certain insects attack the wood of living trees, especially if there are any wounds or dead branches through which entrance is easily gained.

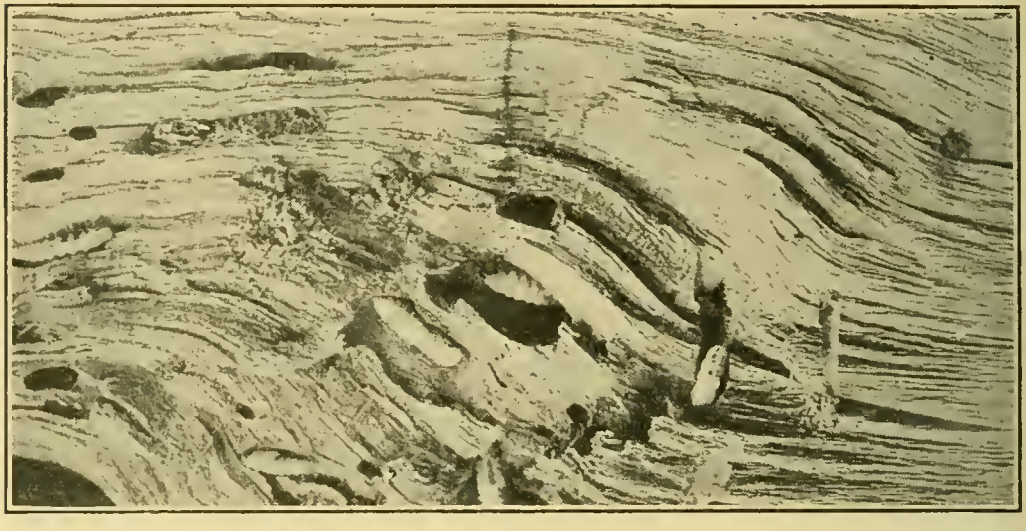

FIG. 97.—Injury to maple wood by round-headed borer (*Parandra brunnea* Fab.). (*Courtesy, Bureau of Entomology.*)

The oak timber worm makes "pinholes" through the wood in all directions. The chestnut timber worm is so common that few chestnut trees remain unaffected by it. It is responsible for a separate grade of lumber known as "sound wormy chestnut." Some ambrosia beetles attack oak, beech, elm, and other hardwood trees. The carpenter worm makes holes in oak sometimes as large as 1½ inches in diameter one way and ¾ inch the other way. Numerous other insects attack the wood of living trees, while some confine their attack to dead and dying trees.

(*b*) *Attack on Unseasoned Products.*—Some insects attack only unseasoned wood with the bark on because the young must hatch and begin their life activities in the inner bark. Later

[1] An insect passes through three stages usually: The larvae, or grub, which hatches from the egg; the pupa, or transition stage during which time it changes from a grub to a third or adult stage when it has wings, legs, and hardened body parts.

the larvae enter the sapwood which they riddle with their galleries. The infestation may occur in the logs or in the sawed lumber if the bark is not removed.

Obviously such destruction can be prevented by peeling or by working up spring- and summer-felled timber soon after it is cut, and fall- and winter-felled timber before March or April when the egg-laying adults become active. Storing the logs in water as in a log pond will also prevent insect attack.

Certain insects, particularly ambrosia beetles, attack unseasoned hardwood lumber even when the bark is removed, especially when piled so as to retard drying. Heavy pieces of hardwood, on account of their slow drying, preferably should be

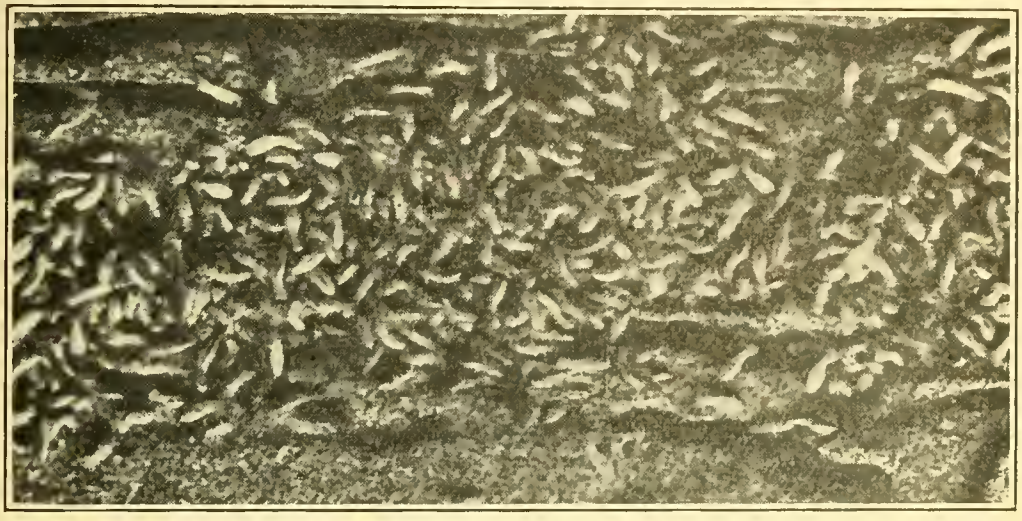

FIG. 98.—"White ants" (*Reticulitermes.*) infesting yellow pine flooring at Washington, D. C. (*Photograph, Courtesy, Bureau of Plant Industry.*)

cut in winter so that they will be partly seasoned by spring, when the insects become active, and any lumber cut in the spring and summer months should be piled so as to dry as rapidly as possible if there is any danger of attack by these beetles. Large quantities of logs, pulpwood, bolts, staves, ties, and mine props are seriously damaged each year by the ravages of insects.

Termites, or "white ants," are very destructive to unseasoned and to some extent to seasoned wood in warm climates. They prefer wood which is somewhat damp, as beams on the ground or set in masonry, porch posts and approaches, flooring, studding, and other woodwork to which access may be had from moist wood or from the ground (Fig. 98). These "white ants" eat out the greater part of the interiors of such woodwork leaving only a

thin shell which may give way when to all outward appearances it is perfectly sound. "White ants" can be kept out of buildings by having all the woodwork well above the ground, and by not

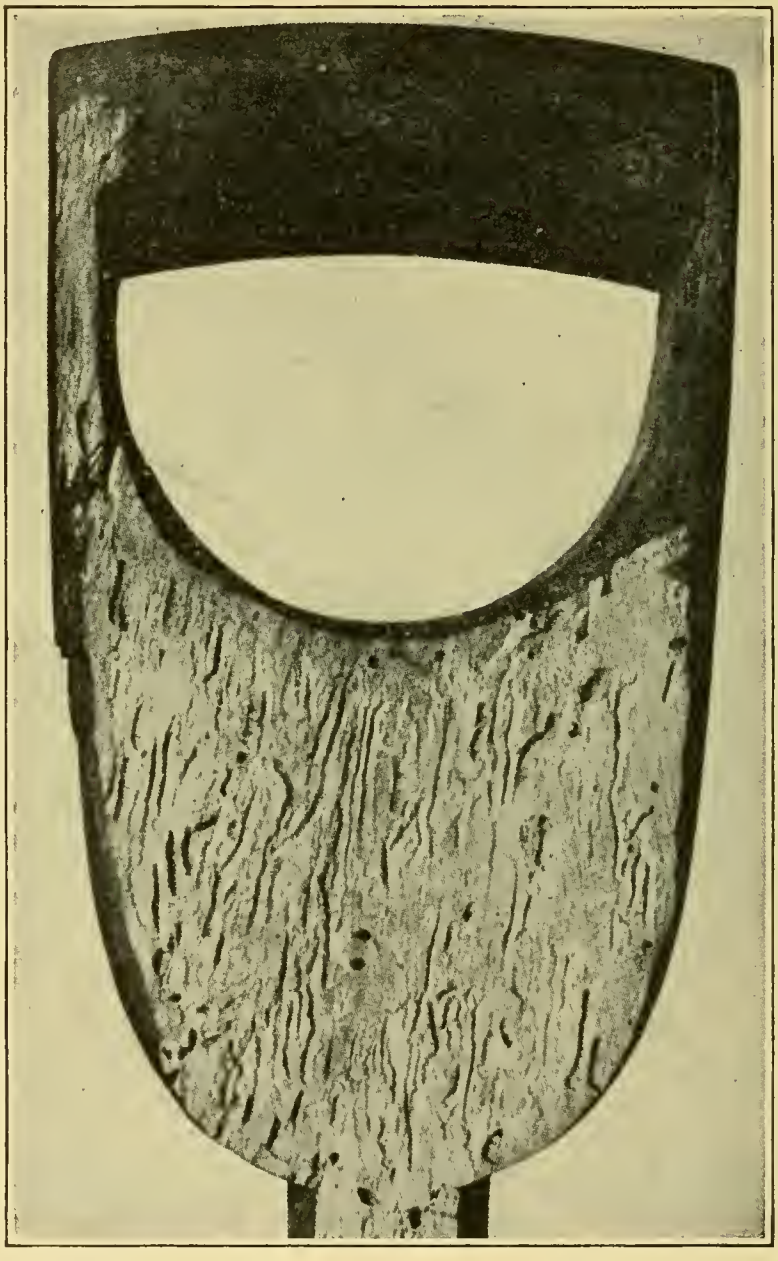

FIG. 99.—Powder-posted ash shovel handle with surface wood cut away to show burrows of larvae within; work of *Lyctus planicollis*. (*From United States Department of Agriculture Farmers' Bull.* 778, "*Powder-post Damage by Lyctus Beetles to Seasoned Hardwood.*")

setting any beams or posts *in* mortar or cement but *on* cement, brick, or stone piers or walls. If it is necessary to place timbers in close proximity to the soil, they should be given a preservative treatment with coal tar creosote which will also retard decay.

"White ants" are not true ants although they live in colonies and have a high social development. They shun the light and, therefore, are rarely seen.[1]

(*c*) *Attack on Seasoned Products.*—Powder-post beetles are injurious to seasoned stock, especially hickory, ash, and oak, although only the sapwood is attacked. Therefore, by separating the stock into heartwood and sapwood classes, only the sapwood stock need be watched for insect damage. Implement handles, wagon stock, ladder parts, and wooden parts of agricultural machinery are especially subject to damage, because ash, hickory, and oak are largely used in their manufacture. Figure 99 shows the work of these insects in an ash shovel handle.

Extensive damage by powder-post beetles may largely be prevented by inspecting the stock once a year and burning all infested material or by dipping it in kerosene if it is not seriously damaged. All old stock should be disposed of and all rubbish around the storehouses cleaned up. Two coats of hot linseed oil applied to finished stock will prevent attack by powder-post beetles. Hot creosote is also effective and can be used where the brown stain of the creosote is not objectionable.[2]

94. Marine Borers.—Timbers used in marine construction, such as the hulls of ships, wharves, docks, etc. are subject to attack by several kinds of marine borers. These are of two distinct groups, the "shipworms" or mollusks,[3] and "wood lice" or crustaceans.[4] The xylotria is one of the most destructive of the "shipworms" in American waters. While still young it enters the wood by forming a very small hole, but once in the

[1] See SNYDER, T. E., "White Ants as Pests in the United States and Methods of Preventing their Damage." United States Department of Agriculture *Farmers' Bull.* **1037.**

For further information concerning the prevention of insect injury to forest products consult the publications of the Bureau of Entomology, especially the following:

HOPKINS, A. D., "Insect Depredations in North American Forests." *Bull.* **58,** part V.

HOPKINS, A. D., "Insect Injuries to Forest Products." *Circular* **128.**

SNYDER, T. E., "Insect Damage to Mine Props and Methods of Preventing Injuries." *Circular* **156.**

[2] See HOPKINS, A. D., and SNYDER, T. E., "Powder-post Damage by Lyctus Beetles to Seasoned Hardwood." United States Department of Agriculture *Farmers' Bull.* **778.**

[3] The mollusks are the group to which the oysters and clams belong. However, not all shipworms are entirely enclosed in their shells.

[4] Crustaceans are the group to which crabs and lobsters belong.

wood it makes the excavation larger to accommodate its growing body which may be from several inches to several feet in length, and from ¼ to 1 inch in diameter.

The teredo which is widely distributed in salt water in many parts of the world is a similar but smaller shipworm. It attains a

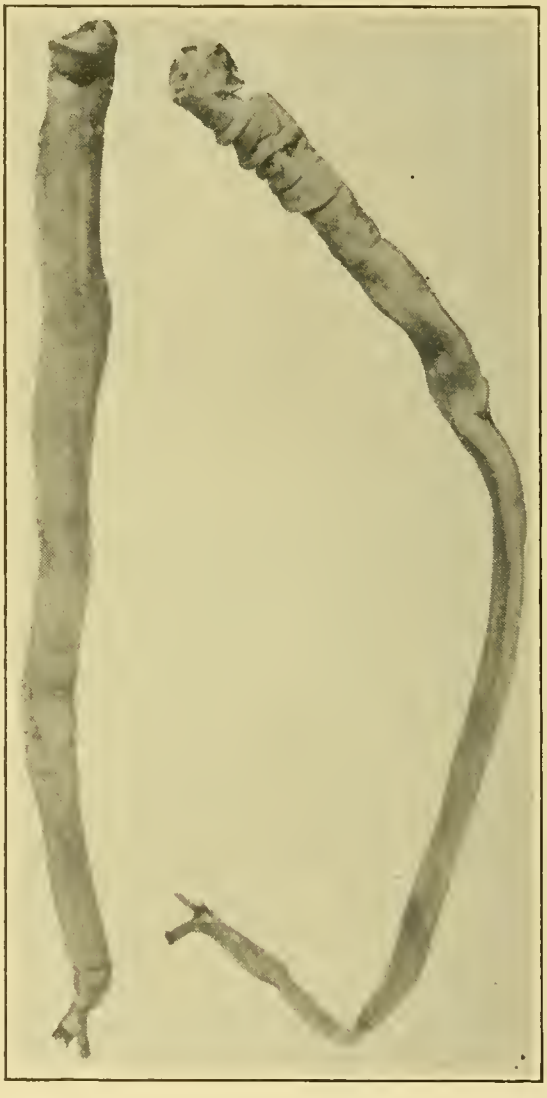

FIG. 100.—*Teredo navalis* from Porto Costa, Cal., natural size. (*Reproduced by permission from the first report of the San Francisco Bay Marine Piling Committee, Plate* 28, *Fig.* 4, *from photograph by C. A. Kofoid.*)

size of 4 to 10 inches in length and from ¼ to ⅜ inch in diameter (Fig. 100). Like the xylotria, when it enters the wood it is exceedingly small but once in the interior it grows rapidly, making an excavation about the size of a lead pencil.

Among the crustaceans the limnoria are the most destructive. Although not larger than a kernel of rice they attack wood in

countless numbers (Fig. 101). The sphaeroma is a larger crustacean resembling very much in size and general appearance the common sow-bug found in damp places. Another crustacean, known as chelura, is only a little more than ⅛ inch in length (Fig. 102). These crustaceans penetrate the wood only a short

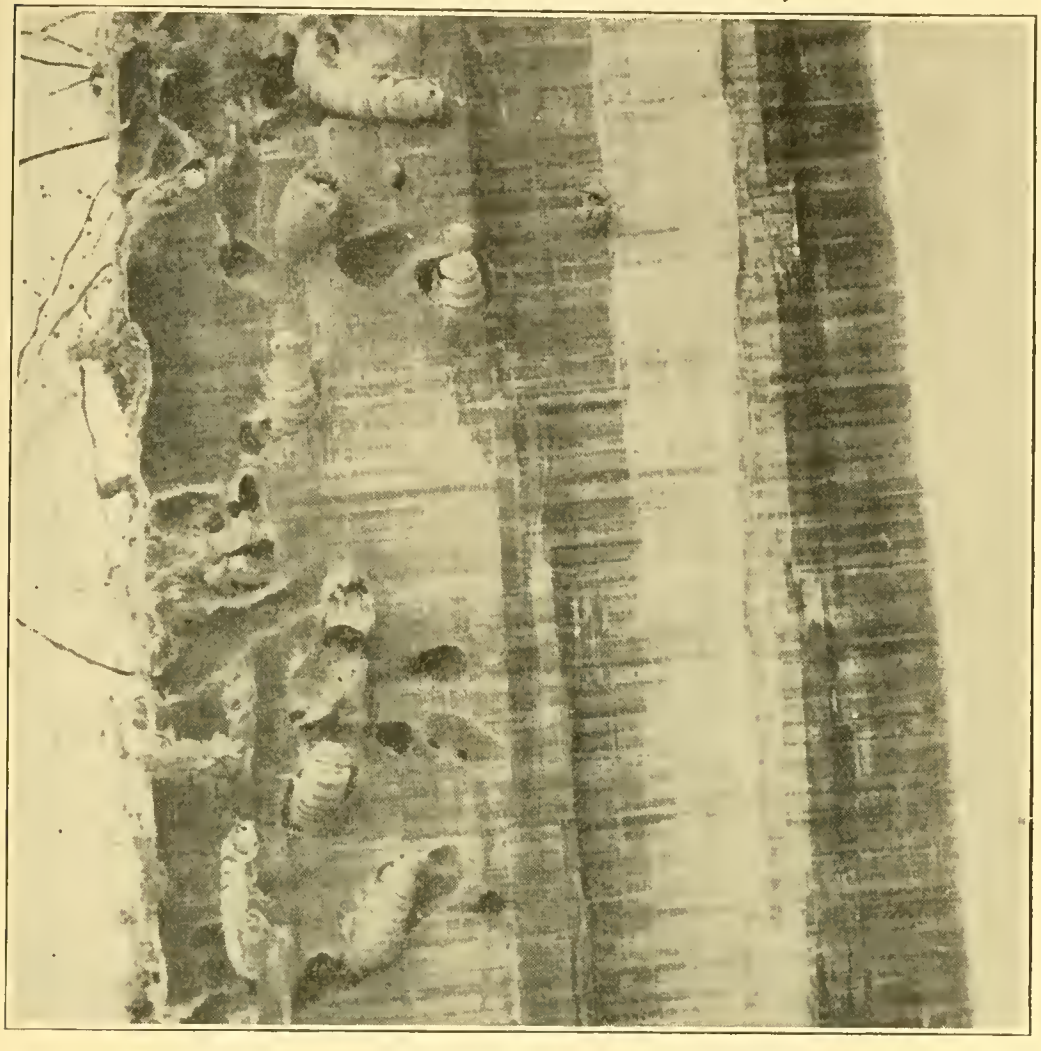

FIG. 101.—*Limnoria* in place attacking wood. Magnified 5 diameters. (*Reproduced by permission from the first report of the San Francisco Bay Marine Piling Committee, Plate* 32, *from photograph by C. A. Kofoid.*)

distance, but as the water wears away the perforated surface layers they recede into the wood, eventually wearing it away and weakening it seriously.

All of the marine borers apparently excavate the wood primarily for shelter and not for obtaining food from it. The most practical means for checking injury to piling, etc. by marine borers is to give the timbers a heavy treatment of coal-tar creo-

sote, although this does not insure absolute protection. Figures 103 and 104 show damage to wood by marine borers.

95. Fire.—By referring to Art. **59** it will be seen that relatively high temperatures are necessary for wood to ignite; that at the

FIG. 102.—*Chelura terebrans*, male, from Charleston, S. C., dorsal view, magnified 16.5 diameters. (*Reproduced by permission from the first report of the San Francisco Bay Marine Piling Committee, Plate* 35, *Fig.* 1, *from photograph by C. A. Kofoid.*)

lower temperatures at which ignition will take place considerable time is required before wood will burst into flame, but at higher temperatures all woods will ignite quickly when in their natural condition; and that dry wood will ignite more readily than moist wood, and rotten wood more readily than sound wood. Since

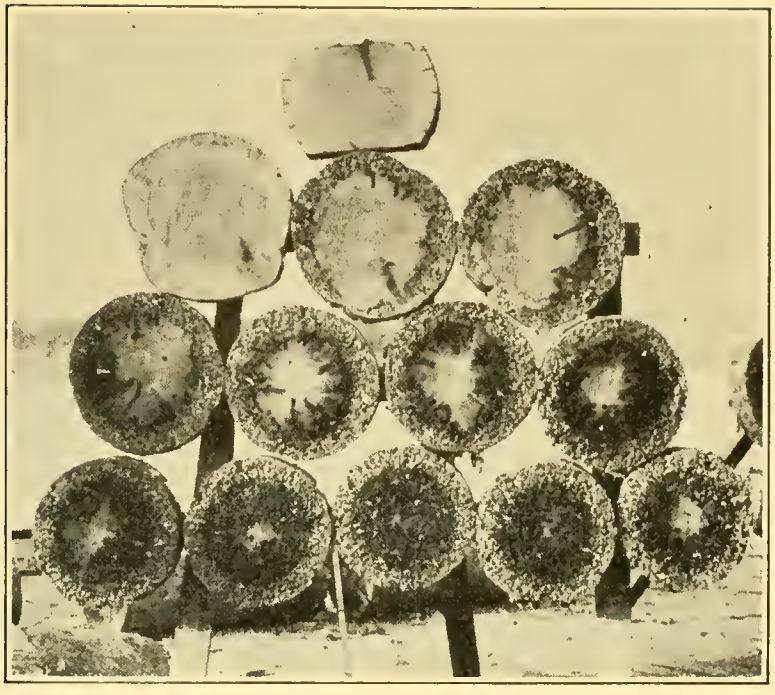

FIG. 103.—Attack by marine borers of fender pile, Shell Oil Company dock, Martinez, California. Sections three feet apart, mud line to high water. November, 1920. (*Reproduced by permission from "Report on the San Francisco Bay Marine Piling Survey."*)

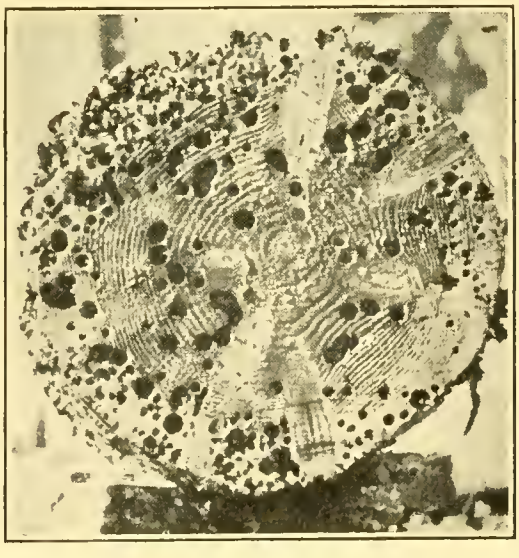

FIG. 104.—Section of pile from Richmond Municipal Pier, San Francisco Bay. Driven, December, 1917; broken out, July, 1920. Note large tubes of *Xylotria* and smaller ones of *Teredo navilis*. *Limnoria* and *Sphaeroma* were also present. (*Reproduced by permission from "Report on the San Francisco Bay Marine Piling Survey."*)

wood is combustible, its use as a construction material in dry places meets with serious objections, especially when used in the crowded sections of cities, in large store and office buildings, hotels, theaters, hospitals, railway coaches, and other structures in which many lives would be endangered in case of fire.

Although wood construction is indirectly responsible for a large amount of the property loss in fire it is by no means the only contributing factor. Carelessness, improper protection, other

FIG. 105.—Ruins of a concrete-block store building after a fire.

inflammable materials, and the crumpling of stone and buckling of steel under high temperatures add considerably to the yearly fire loss. It is estimated that about two-thirds of the annual fire loss in this country consists of frame buildings and their contents, but this enormous loss cannot be attributed wholly to the wooden structure, because the other third of the loss occurs principally in brick, stone, and concrete buildings which are far less in number. Figure 105 shows the ruins of a concrete-block building after a fire.

CHAPTER X

PROTECTION OF WOOD AGAINST DECAY AND FIRE

The chief drawback to the almost universal use of wood as a structural material is its susceptibility to decay and fire. If it were not for this drawback, timber could be used for almost any structure because it can be secured in large enough sizes and in sufficient quantity to give the necessary strength. In spite of this handicap, wood is used for a large variety of structures. By increasing its resistance to decay and fire by preservative treatment its usefulness cannot only be extended considerably but frequent replacements can be avoided, which are usually more expensive than the cost of the first installation.

Furthermore, the saving of timber by proper preservative treatment decreases the annual timber consumption. The life of wood subjected to decay can be more than doubled on the average by properly treating it with preservatives. If all of the 9 billion or more board feet of timber which decay each year were properly treated, an annual saving of about 5 billion board feet could be effected. Nor is this all. Woods which heretofore were considered inferior—such as red oak, sap pine, cottonwood, box elder, white fir, and other non-durable kinds—could be used more extensively for ties, posts, and other timbers in places where decay of untreated wood may take place. Thus more of the desirable woods—such as white oak, locust, cypress, and redwood—would be left for higher-class work or for uses for which preservative treatment is impracticable.

Although wood preservation is not practiced so widely as its success justifies, it is a growing industry, and eventually as timber becomes still higher priced and the value of wood preservation is better understood, properly treated woods will probably be available at many lumber yards.

It was not until 1875 that modern timber preservation was begun in this country. In that year a creosoting plant was erected at West Pascagoula, Miss., for the treatment of timbers used by the Louisville and Nashville Railroad. In 1904 there

were 33 treating plants in operation in the United States and 250,000,000 board feet of timber were treated, while in 1921 there were 122 plants in operation and 2,400,000,000 board feet were treated. This shows that the demand for treated timber is increasing rapidly and that wood preservation has passed beyond the experimental stage.

96. Factors Influencing Decay.—In the previous chapter we have seen that four conditions are necessary for decay: warmth, air, moisture, and wholesome food for the fungus. If one of these conditions is eliminated, decay cannot take place. It is not practical as a rule to regulate the first two,[1] but the moisture content and food can often be modified sufficiently to retard decay.

As a precaution against introducing decay into buildings and other structures, the lumber should be selected only from yards or mills where sanitary lumber storage conditions prevail. Lumber which has been stored over low wet ground, or on partly decayed skids, or in yards where rotten wood and rubbish are abundant may become seriously infected with decay before it reaches the consumer. Such material may continue to decay after it is put into place and also transmit the fungus to other parts of the structure.[2]

97. Influence of Seasoning on Decay.—As has been stated in Art. **88** at least 20 per cent of moisture is necessary as a rule for wood to decay. Thoroughly air-seasoned material and kiln-dried stock usually contain less moisture and are immune from decay as long as they are kept in that condition.

If dry wood, even that which has been kiln dried, is again allowed to absorb sufficient moisture, it is subject to decay. Therefore, nothing is gained as far as durability is concerned by seasoning posts, poles, and ties which are to be put into damp soil, for in a relatively short time they will absorb sufficient moisture from the ground so that decay can take place.

[1] O. P. M. Goss, Consulting Engineer for the West Coast Lumbermen's Association, states in "Structural Timber Handbook on Pacific Coast Woods" that if Douglas fir wood pipe is filled with water under a 20-foot head it will not decay. The water pressure keeps the pipe saturated, thereby excluding air.

[2] See HUMPHREY, C. J., "Timber Storage Conditions in the Eastern and Southern States with Reference to Decay Problems." United States Department of Agriculture *Bull.* **510.**

If wood is once infected with decay, air drying will not destroy the fungus, but will only keep it dormant, in which condition it may remain many years and become active whenever sufficient moisture is available. The temperature of dry kilns, however, is usually sufficient to kill wood-destroying fungi. Kiln-dried material, therefore, must be infected anew as a rule, and must reabsorb sufficient moisture before decay can set in.

Instances have been known where non-durable woods, such as maple and black gum, decayed before they had time to season. In such cases the wood was in large pieces and was not properly piled so that the circulation of air was retarded, or climatic conditions were such that seasoning could not take place.

98 Other Preservative Measures Based on the Use of Non-poisonous Materials.—Painting is commonly resorted to as a means of keeping out decay. Its effectiveness, however, depends upon certain conditions. If the wood is kept so well painted, especially at the joints, that it does not absorb a great deal of moisture during damp and rainy weather, painting may retard decay. On the other hand, painting wood may hasten its decay if the wood can absorb moisture through checks or unprotected portions. Under such conditions the painted surfaces will not permit of rapid drying, and, consequently, the wood will be kept moist and in excellent condition for decay, for a longer time than if left unprotected.

Crude oil is not poisonous to wood-destroying fungi. It is used to some extent as a preservative in mixture with coal-tar creosote, and in this way it is very successful. It cannot safely be used by itself, however, because experience has shown that it is not reliable in preventing decay.

It is an old practice in the building of wooden ships to fill the space between the inner and the outer planking of the sides with salt. The salt keeps the wood moist and the joints tight, and at the same time, because of its high concentration, prevents decay.

A unique way of treating pine for fence posts is practiced in Montana where limber pine and whitebark pine are used. Young saplings of the proper size for posts are peeled in the spring while still standing. Immediately pitch exudes covering the entire surface. In the course of several months the post becomes seasoned and the pitch hardened. The tree is then cut and the

ends are smeared with tar. After this treatment, fungi find it difficult to attain access to the wood. Some posts so treated are said to have lasted 20 years in the ground, although definite data as to the value of this treatment are lacking.

Occasionally the butts of fence posts are charred to retard decay, but service tests made by the Forest Products Laboratory on fences of charred and untreated posts have shown no advantage gained from charring.

99. Preservatives Which Are Poisonous to Fungi.—It has long been known that the presence of certain chemicals inhibits the growth of fungi and bacteria, and prevents decay. The poisonous property of such chemicals is called toxicity. The art of embalming, in which the ancient Egyptians became so proficient, is based on this principle.

On account of numerous practical considerations only a few preservatives are of importance in treating wood. The toxic preservatives commonly used can be divided into two groups: (*a*) Water-soluble, and (*b*) those that are of an oily nature. The water-soluble preservatives usually are inorganic chemicals which are shipped in concentrated form and are diluted when used. They enter wood comparatively easily but are also easily leached out, and, therefore, are not well suited for timbers in very wet locations. Of the oily preservatives, the most widely used one is coal tar creosote. The following are the principal wood preservatives:

(*a*) *Water-soluble.*—Zinc chloride is the most extensively used of the water-soluble preservatives. The amount used annually varies with its price, the price of creosote, and other factors. Approximately 50,000,000 pounds were used in the treatment of timber in the United States in each of the years 1920 and 1921. The use of zinc chloride increased more rapidly than that of any other preservative during the decade preceding 1921. Timber in various forms equivalent to 1,123,000,000 board feet was treated with zinc chloride in 1921. It does not attack iron seriously and is very effective in preventing decay, a 3 to 4 per cent solution being the strength usually injected into timber. The extent of its penetration into the timber can be determined by means of various chemical tests.

Copper sulphate (blue vitriol) is highly toxic, comparatively cheap, readily soluble, and on account of its blue color shows how far it has entered the wood. Because it attacks iron, and,

therefore, cannot be used in iron and steel apparatus, and because it is easily leached out, it is used very little.

Mercuric chloride (corrosive sublimate) is one of the most toxic of chemicals. It is less soluble than copper sulphate, and, therefore, not so easily leached out. It also attacks iron severely. Because of its highly poisonous nature it is dangerous to handle. It was first used extensively by Kyan, in England, and its use in wood preservation is now known as the Kyanizing process. It is not widely used in the United States.

Sodium fluoride has been used only recently. It is more toxic by weight than zinc chloride and does not attack metals. If

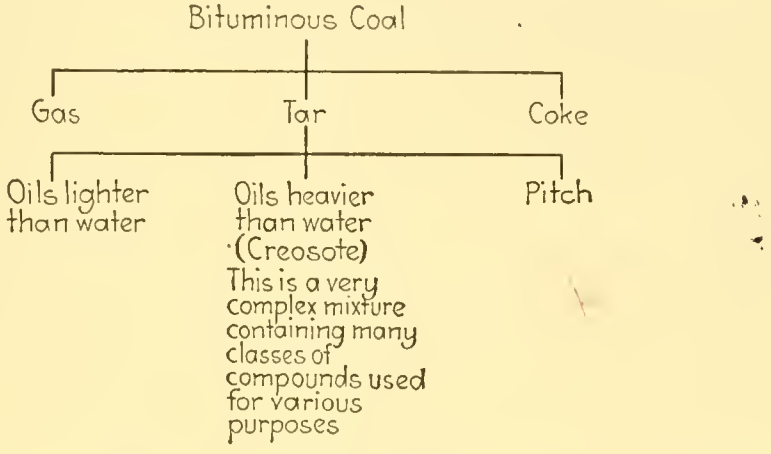
Bituminous Coal
Gas
Tar
Coke
Oils lighter than water
Oils heavier than water (Creosote) This is a very complex mixture containing many classes of compounds used for various purposes
Pitch

FIG. 106.—Diagram showing derivation of creosote from the destructive distillation of soft coal.

it were not for its high price, it might become of considerable commercial importance as a wood preservative.

(*b*) *Preservatives of an Oily Nature: Creosotes.*—Commercial creosotes used for wood preservation are oils heavier than water obtained from the distillation of tars. The tars are derived from the destructive distillation of coal or wood, or by the cracking of petroleum at very high temperatures.

Coal-tar creosote (dead oil of coal tar) is the most important of the oily wood preservatives. About 76,500,000 gallons were used in 1921 in the United States, and about 1,183,000,000 board feet of timber were treated in that year.

The derivation of coal-tar creosote is shown graphically in Fig. 106. The tar from which it is made is obtained from the destructive distillation of bituminous or semibituminous coal a t by-product coke ovens and coal gas plants. It is composed of numerous compounds which boil at different temperatures. The

fraction which distills below 275° C. is much more toxic than that which distills at higher temperatures. The toxic compounds are somewhat soluble in water and probably leach out in the course of time when in contact with water. The higher fractions, although less toxic, are practically insoluble in water and retard the leaching out of the lighter oils. Coal-tar creosote is sufficiently toxic for wood preservation, is not dangerous to handle, and does not attack iron.

Water-gas-tar creosote is obtained by the distillation of tar produced as a by-product from the petroleum used in the manufacture of carbureted water gas. It contains many of the compounds found in coal-tar creosote but differs from the latter in containing practically no tar acids and tar bases. It is not so toxic as coal-tar creosote and is used in much smaller quantities.[1]

Wood-tar creosote, produced by the destructive distillation of wood, has been used to some extent as a wood preservative. Its high price, corrosiveness, and the fact that it has not been obtainable in large quantities in standard grades have prevented its widespread use as a preservative, although it is used in the manufacture of creosote stains which are claimed to have a preservative action on wood.

100. Choice of Preservatives.—The choice of a preservative depends upon its availability, cost, toxicity, effect on metals, permanency, ease with which it enters wood, electric conductivity, susceptibility to subsequent finishes, odor, and the effect on the strength of wood. A discussion of the factors affecting the penetration of preservatives is contained in Art. **23.**

First of all, a preservative must be available in large quantities in order to become of general use. Next, the cost must not be excessive. The cost of preservatives varies greatly because of the fluctuations in market prices. Before the beginning of the World War coal-tar creosote could be obtained at from 7 to 12 cents a gallon within reasonable distance from the distributing centers, and zinc chloride at from 2½ to 4 cents a pound. In 1922 the average price paid for creosote was about 15 cents a gallon and that of fused zinc chloride from 4 to 6 cents a pound when purchased in large quantities.

[1] BATEMAN, ERNEST, "Coal-tar and Water-gas-tar Creosotes: Their Properties and Methods of Testing." United States Department of Agriculture *Bull.* **1036.**

For railroad ties, bridges, foundation timbers, cross-arms, paving and flooring blocks, posts, and poles, used where leaching may take place, and where the wood is not to receive any other finish, coal-tar creosote is the most effective preservative. As far as is known, any good coal-tar creosote will preserve wooden structures for use on land against decay for the full length of their mechanical life, provided the material is treated properly.

For the interiors of factories and warehouses where humid conditions prevail but where leaching cannot take place and the wood is to be painted, some of the water-soluble salts are more desirable. When used for treating railroad ties, it has been found that these inorganic salts, like zinc chloride, increase the electric conductivity from the rails to the ground, thereby interfering with the block-signal system although when only six or seven ties per rail length are treated with zinc chloride it has no appreciable effect.

Creosotes are all dark colored thus precluding the subsequent use of lighter colored paints; in fact paints do not adhere well to creosoted timber. On rough work, such as silos, the creosote itself serves as a stain. The odor of creosote often is objectionable around buildings, although the fumes probably have antiseptic properties.

The preservatives commonly used do not affect the strength of wood in the concentrations used. If any reduction takes place in the strength of treated wood, it is most likely to be due to the method of treatment, such as the use of high temperatures or rapid drying. For the effect of preservative treatments on the strength of wood see Art. **52.**

101. Preservative Processes. (*a*) *Non-pressure Processes.*— The simplest and cheapest method of applying preservatives to woods is to brush or spray them on, but it is also the least effective. Figure 107 illustrates the brush method of treating poles. Water-soluble preservatives are not considered suitable for use in this way, and, therefore, only oils should be used. The timber should be thoroughly seasoned to insure at least a slight penetration, and to prevent checks from forming after treatment. The preservative should not be applied sparingly but should be allowed to flow into every check and opening. To do this successfully the oil should be heated to from 200 to 220° F., and the work should be done in warm weather. If the preservative comes into contact with cold wood, it does not penetrate well.

It is essential that two coats be applied, allowing the surface to dry thoroughly before the second coat is put on.

This method requires a minimum of equipment—a large brush, a bucket to hold the preservative, and a means of warming it. The oil may be warmed over an open fire, but care must be taken not to allow it to ignite. When considerable work of this kind is to be done, some form of heater should be provided. The oil should not be allowed to boil. It is desirable to use a thermometer to keep it at the proper temperature.

The brush method can be used to advantage in the construction of buildings by coating the ends of posts or timbers set in

Fig. 107.—Brushing preservatives on chestnut pole butts. (*Courtesy, U. S. Forest Service.*)

damp places or in masonry or where timbers join or intersect, since decay usually sets in first at such points.

The advantages of the brush method are that it is cheap and rapid, and that little or no preservative need be left over. The disadvantage is its low efficiency on account of allowing decay to enter in subsequent checks and places where the surface has been bruised in handling.

Dipping the timber in a tank of hot creosote is more effective than the brush treatment because of the greater certainty that the oil will enter all cracks and crevices, and because the wood can be kept in contact with the warm oil for a longer period so that greater penetration may take place. This method, therefore, can be used in winter if some means is provided for keeping the tank of oil heated. A steam pipe from a boiler is a safe

and uniform method of heating, although a fire may be built underneath the tank (Fig. 108). The disadvantages of this method of preservation are that at best only a slight penetration is secured, a tank is required, and a considerable quantity of oil is necessarily left over after the treatment is completed.

A modification of the dipping method, known as the open-tank process,[1] gives more satisfactory results than mere dipping. It consists in placing the timber to be treated wholly or in part (this method lends itself especially to the treatment of the butts of fence posts and telephone poles) in a tank of creosote heated

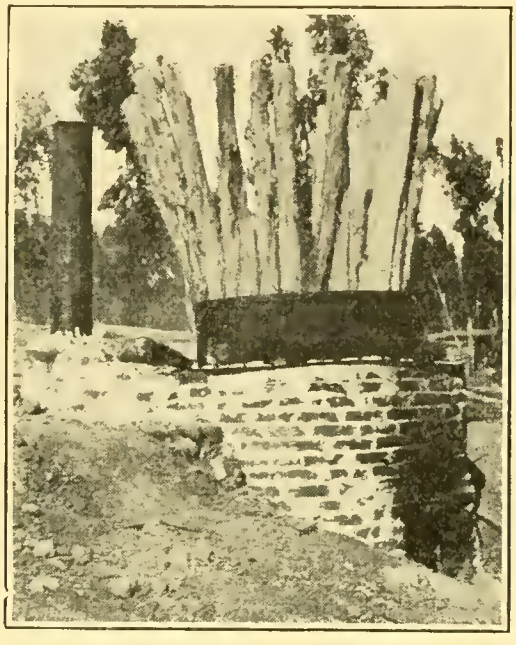

FIG. 108.—Open tank with brick fire box for treating poles. (*Courtesy, U. S. Forest Service.*)

to from 180 to 220° F. for an hour or longer. The timber is then quickly transferred to another tank containing cooler creosote (about 100° F.). In the hot bath the air in the wood expands and much of it bubbles to the surface. When the wood is placed in the cooler creosote, the air contracts drawing the oil into the wood, thus obtaining a deeper penetration than is

[1] For a more detailed statement of the brush, dipping, and open-tank methods see HUNT, G. M., "The Preservative Treatment of Farm Timbers." United States Department of Agriculture *Farmers' Bull.* **744.** This may be obtained free, as long as the supply lasts, from the Division of Publications, U. S. Department of Agriculture, Washington, D. C.

See also MCDONALD, G. B., "Preservative Treatment of Fence Posts," Iowa State College (Ames, Iowa) Agricultural Experiment Station *Bull.* **158.**

obtained by the hot bath alone. To avoid the use of two tanks the hot creosote may be allowed to cool with the timber in it. Where speed is not essential, this method can be worked with economy of time by heating a batch of material in the morning and allowing it to cool during the day and heating another batch in the evening and allowing it to cool overnight.

The advantage of this method is that the atmospheric pressure can be applied to force the oil into the wood. In this way, a penetration of ¼ inch, or of the entire sapwood in some species, may be obtained. Furthermore, by regulating the length of time the wood is in each of the baths the amount of oil absorbed can be regulated. The disadvantages are that more oil is required than by the dipping process, and the treatment takes longer.

For all the non-pressure methods of treatment, water-soluble preservatives are not recommended, as a rule, because of the ease with which they may be leached out. Zinc chloride treatment by the open-tank method may sometimes be used to advantage for mine timbers or in buildings where only moderate moisture conditions are found, and where creosote is objectionable on account of its odor and color.

The Kyanizing process, that is, steeping timber in a solution of bichloride of mercury, is used to a limited extent in this country. The wood is submerged in a 1 per cent solution of bichloride of mercury for a day, plus a day for each 1 inch in thickness. The solution rarely penetrates more than ¼ inch, and like other water-soluble preservatives may leach out. On account of the extremely poisonous nature of this preservative, and because it corrodes iron and steel, it is used very little in this country.

In order to make the non-pressure processes effective all the bark should be removed from the timber to be treated, since bark seriously hinders the penetration of liquids, and the wood thoroughly seasoned. Some woods, in seasoning after they are peeled, become glossy on the surface, probably because of resin and other substances exuding and hardening. This gloss, or "casehardening" as it sometimes is called, hinders the penetration of preservatives and should be removed at least at the ground line of posts and poles where the greatest protection is needed.

(*b*) *Pressure Processes.*—The injection of preservatives into wood under pressure gives the most satisfactory results but also requires a considerable outlay for equipment. Ties, piling,

and timbers are treated almost exclusively by these processes, although for the treatment of poles the open-tank methods are used to a greater extent. The principal advantages of the pressure methods are: A deeper penetration can be secured thus making the treatment more effective; there is little loss of preservative through evaporation during treatment; and unseasoned wood can be treated.

For these processes long cylinders from 6 to 8 feet in diameter and up to 150 feet long are used. Into these cylinders small

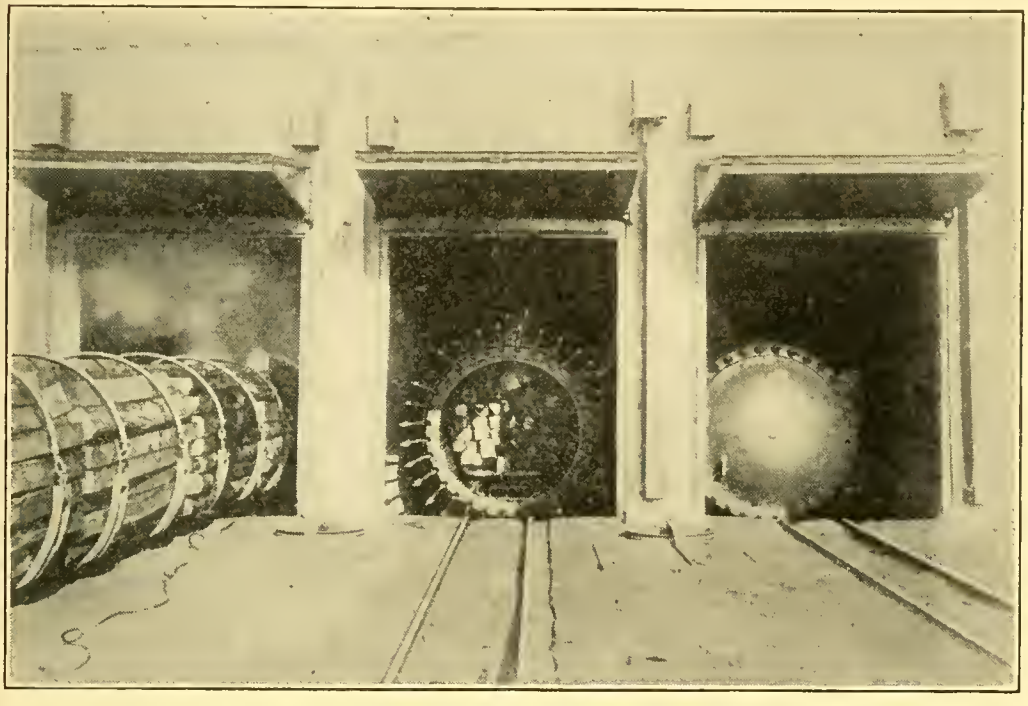

FIG. 109.—Tie-treating plant showing "buggies" of ties entering cylinder, cylinder fully charged, and cylinder closed as during treatment.

cars or "buggies" loaded with ties, cross-arms, paving blocks, or whatever wood is to be treated are run on steel rails (Fig. 109). When the cylinders are filled with a charge, the end doors are tightly closed, thus permitting the wood to be surrounded by a preservative and pressure to be applied.

The following are the most common pressure processes used in this country:

The Bethell Process: This process is so named after the English inventor, John Bethell. If air-seasoned timber is used, a vacuum is first drawn in the cylinder for ½ hour to several hours. If green timber is used, it is first steamed for several hours to heat

it through, and then when the preliminary vacuum is drawn some of the moisture is removed. Creosote is then allowed to run into the cylinders containing the charge, and heated to 180 to 200° F. while a pressure of 100 to 180 pounds is applied to the liquid. This forces the creosote into the cells, and produces a good absorption, although both the absorption and penetration depend upon the kind of timber. When the gauges show that the desired amount of oil (6 to 16 pounds per cubic foot, except for protection from marine borers which requires 18 to 24 pounds per cubic foot) has been injected into the wood, the oil is drained off and the timber is allowed to drip for a short time before it is removed. Often a vacuum is again drawn after the pressure period so as to hasten the drip. This process is also known as the full-cell process on account of the large amount of preservative taken up by the wood. This method gives the most effective results. It also is the most expensive.

The Boiling under Vacuum Process: After the cylinders are charged, the timber is surrounded by creosote which is gradually heated by means of steam coils to 190 to 210° F. for 10 to 60 hours. During the early stages of the heating period a preliminary vacuum is drawn to hasten the vaporization of some of the moisture in the wood. The moisture rises to the surface in the form of vapor and passes off through a condenser. A pressure of 120 to 180 pounds per square inch is then applied until the desired absorption is secured (10 to 16 pounds per cubic foot). In treating air-dry material lower temperatures and pressures are used. This process is used to a considerable extent on the Pacific Coast for treating green Douglas fir timbers, poles, and ties.

The Lowry Process: This is similar to the Bethell process except that no preliminary vacuum is drawn. When the final vacuum is drawn, the air in the wood expands and forces some of the excess oil out of the timber. This is, therefore, known as an empty-cell process, for only the cell walls are treated, the cell cavities remaining practically empty. The absorption ranges from 6 to 10 pounds per cubic foot.

The Rueping Process: This is similar to the Lowry process except that a preliminary air pressure is applied, and then, without relieving the air pressure, the oil is injected. At the final vacuum a certain amount of drip is recovered, as in the Lowry process. This is also known as an empty-cell process. The absorption ranges from 4 to 6 pounds per cubic foot.

The Burnett Process: This is similar to the Bethell process in that a preliminary vacuum is drawn but no final vacuum is drawn or only a slight vacuum to prevent dripping when the charge is drawn from the cylinder. A zinc chloride solution is used. The strength of the solution is regulated so that when the timber is fully treated it will contain close to ½ pound of zinc chloride (not including moisture) per cubic foot.

The Card Process: In this process a mixture of about 80 per cent zinc chloride (3 to 5 per cent solution) and 20 per cent creosote is used. This is cheaper than pure creosote and more effective than zinc chloride alone because of the added preservative effect of the oil. Since oil and water do not mix well, the solution in the cylinders must be continually agitated by means of a pump. The steps are similar to those in the Bethell process. Usually the timber is treated so that about ½ pound of dry zinc chloride and 2 or 3 pounds of creosote are injected per cubic foot.

102. Choice of Wood for Preservative Treatment.—For preservative treatment, it is best to select from among those species of woods which are available at a reasonable price such kinds as will take preservative treatment easily and which will otherwise fulfil the requirements for size, strength, etc. There is considerable difference in the manner in which preservatives will penetrate wood as has been pointed out in Art. **23.** Among both hardwoods and softwoods some species are easy to treat and some are difficult to treat. With few exceptions sapwood takes preservatives more readily than heartwood. This is fortunate, since sapwood is not durable, but by proper treatment it can be made fully as durable and even more so than heartwood. In treating fence posts better results often may be obtained by using round posts instead of split or sawed posts because the round posts afford a complete layer of sapwood in which good penetration can be secured under proper conditions.

According to results of experiments made at the Forest Products Laboratory, native commercial woods can be classified with respect to ease of treatment as in Table XXIV. In the tests on which this table is based creosote was used and pressure was applied to the preservative.

It usually is more economical, when preservatives are to be applied, to use some of the inexpensive and less durable kinds of wood such as sap pines, box elder, soft maple, beech, gum, and

TABLE XXIV.—RELATIVE EASE WITH WHICH WOODS WERE IMPREGNATED WITH CREOSOTE UNDER TEST[a]

Hardwoods	*Softwoods*
A. Woods Which Treated Easily	
Slippery elm (heartwood)	Tamarack (sapwood)
White elm (heartwood)	Western larch (sapwood)
Red oak (heartwood)	Jack pine (sapwood)
Chestnut oak (heartwood)	White spruce (sapwood)
White ash (heartwood)	Western yellow pine (sapwood)
Green ash (heartwood)	Douglas fir (sapwood)
Hackberry (sapwood)	Engelmann spruce (sapwood)
Tupelo gum (heart- and sapwood	Lodgepole pine (sapwood)
Red gum (sapwood)	Spruce pine (sapwood)
Wild red cherry (heartwood)	Southern yellow pine (sapwood)
Basswood (heartwood)	
Silver maple (sapwood)	
Yellow birch (heartwood)	
Sweet birch (heartwood)	
Red birch (heartwood)	
White heart beech (heartwood)	
B. Woods Which Were Moderately Difficult to Treat	
Mockernut hickory (heartwood)	White fir (heart- and sapwood)
Hackberry (heartwood)	Sitka spruce (heart- and sapwood)
Rock elm (heartwood)	Noble fir (sapwood)
Chestnut (heartwood)	Lodgepole pine (heartwood)
Black willow (heartwood)	Spruce pine (heartwood)
Largetooth aspen (heartwood)	Southern yellow pine (heartwood)
Sycamore (heartwood)	Engelmann spruce (heartwood)
Sugar maple (heartwood)	Western yellow pine (heartwood)
Silver maple (heartwood)	Jack pine (heartwood)
C. Woods Which Were Difficult to Treat	
Bur oak (heartwood)	Alpine fir (heart- and sapwood)
White oak (heartwood)	Yew (heartwood)
Red heart beech (heartwood)	Douglas fir (heartwood)
Red gum (heartwood)	Tamarack (heartwood)
	White spruce (heartwood)
	Western larch (heartwood)
	Redwood (heart- and sapwood)
	Noble fir (heartwood)
	Eastern hemlock (heart- and sapwood)

[a] From TEESDALE, C. H., "Relative Resistance of Various Conifers to Injection with Creosote." United States Department of Agriculture *Bull.* **101.** TEESDALE, C. H. and MACLEAN, J. D., "Relative Resistance of Various Hardwoods to Injection with Creosote" *Bull.* **606.**

red oak, than some of the more expensive and more durable woods such as cedar, redwood, cypress, locust, and white oak. No matter what kind of wood is used it should be well seasoned to obtain best results especially for non-pressure methods. Preservatives, especially those of an oily nature, will not penetrate wet woods very well.

103. When Preservative Treatment of Wood Is an Economy.—Although any set of timbers may be made more resistant to decay by preservative treatment, such treatment may not always be economical, even though the timbers are to be exposed to the most severe fungous attack. If the timbers are to be in service for a short time only, durability is unimportant, and any kind of preservative treatment would obviously be a waste of money. If, on the other hand, the wood is naturally of low durability and is to be used in a permanent location, it is easy for preservative treatment to show great savings. Between these two extremes there are any number of instances in which it is a more difficult problem to determine whether or not preservative treatment will pay.

If a timber user knows the average life that treated and untreated timbers are giving and the cost of each in place, he can easily compute, with the use of Table XXV, the relative annual costs of maintaining the two. A mine operator may have found, for example, that untreated timbers are giving an average life of 2 years and that their cost in place is $6 per set. Assuming an interest rate of 7 per cent, the table shows that timbers which need replacement every 2 years cost annually $0.553 on every dollar of their cost in place. For the $6 set, then, the annual maintenance cost would be 6 times $0.553, or $3.32. Treated timbers, the user may find, give an average life of 14 years and cost $7.50 per set in place. The annual charge on timbers with a 14-year life is found in the table to be $0.116 on each dollar of their cost in place. The annual cost of maintaining the $7.50 treated set, therefore, would be 7.5 times $0.116, or $0.87. Preservative treatment, then, would save this user annually $2.45 per set.

If a timber user knows the cost of treated and untreated timber and the average life of the untreated timber only, he can estimate how long treated timber would have to last to be as cheap as untreated timber. In the case discussed above, the untreated timber cost $6 in place; the treated, $7.50; and

Table XXV.—Annual Charges on Each Dollar of Cost of Timbers in Place

Interest rate, per cent	Life in years before replacement																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	22	24	26	28	30
4	1.04	0.530	0.362	0.275	0.225	0.191	0.166	0.148	0.132	0.123	0.114	0.106	0.100	0.094	0.086	0.079	0.073	0.069	0.065	0.062	0.060	0.058
5	1.05	0.538	0.367	0.282	0.231	0.197	0.173	0.155	0.140	0.129	0.120	0.112	0.106	0.101	0.092	0.085	0.080	0.076	0.072	0.069	0.067	0.065
6	1.06	0.545	0.374	0.288	0.237	0.203	0.179	0.161	0.148	0.135	0.126	0.119	0.112	0.107	0.098	0.092	0.087	0.083	0.079	0.076	0.074	0.070
7	1.07	0.553	0.381	0.295	0.243	0.209	0.185	0.167	0.153	0.142	0.133	0.128	0.121	0.116	0.109	0.103	0.097	0.092	0.088	0.086	0.083	0.081
8	1.08	0.561	0.388	0.302	0.250	0.216	0.192	0.174	0.160	0.149	0.140	0.133	0.127	0.121	0.113	0.107	0.102	0.098	0.095	0.093	0.090	0.089
9	1.09	0.568	0.395	0.309	0.257	0.223	0.199	0.181	0.167	0.156	0.147	0.140	0.134	0.128	0.120	0.114	0.110	0.106	0.103	0.101	0.099	0.097
10	1.10	0.576	0.402	0.315	0.263	0.227	0.205	0.187	0.173	0.162	0.153	0.146	0.140	0.135	0.128	0.121	0.117	0.114	0.110	0.109	0.106	0.105

Based on the formula, $A = P \dfrac{(1+r)^n r}{(1+r)^n - 1}$, in which A = annual charge.

P = amount of initial investment.

n = number of years in the recurring period (the average life of the timber).

r = the rate of interest expressed decimally.

the untreated timber was lasting 2 years. The annual charge on the untreated set was found to be \$3.32, and since the annual charge on the \$7.50 treated set is to equal this, the equation $7.5 \times y = \$3.32$ may be set up; then y (the annual charge on one dollar expenditure) = $\$3.32 \div 7.5$, or \$0.443. Referring again to the table and looking along the 7 per cent interest rate row, we find that an annual charge of \$0.443 on the dollar falls between the 2-year and 3-year columns and evidently at a point equivalent to about a $2\frac{3}{4}$-year life. It can readily be seen from this that if treatment adds only $\frac{3}{4}$ of a year to the life of the timbers, it would pay for itself, and the user could be sure from the experience of others that it would add much more than this and would, therefore, be profitable.

If untreated timber is giving long life, treatment might not result in great savings. However, very often it might be possible to substitute for such timber a treated lower-grade material that would give as long or longer life with an annual maintenance charge which would compare very favorably with that of the better-grade untreated timber.

104. Uses of Preserved Wood.—The principal uses of preserved wood are as ties, posts, poles, piling, cross-arms, paving blocks for streets and factory or warehouse floors, flooring, bridge timbers, silos, wood stave pipe, sills and posts in buildings, and mine props.

About one-half of all railway ties placed in track each year are treated. The life of such ties often is more than doubled; in fact, well-treated ties fail because of wear rather than decay. Posts and poles, which decay at the ground line rapidly if untreated, can be made to last 30 to 40 years by preservative treatments. Piling, which in marine waters may be destroyed in 2 or 3 years by marine borers, can be made to last 15 or 20 years with heavy injections of creosote. The use of paving blocks without preservative treatment would be impracticable in most cases because of the favorable conditions for decay to which they are exposed. Floors made of creosoted blocks are relatively noiseless and sanitary. Furthermore, they are not so hard to stand and walk on as stone, brick, or concrete. Bridge timbers are especially difficult to replace; but when creosoted, may not need to be replaced for 20 years or more. The pressure creosoted timbers in the bridge over Lake Ponchartrain, La. illustrated in Fig. 110 are still in good condition after 40 years

of service. Silos built of creosoted wood last a long time and do not need painting. Actual tests show that the creosote in the wood does not affect the silage. Wood stave pipe impregnated with creosote can even be used for conveying drinking water after water has run through the pipe for some time.

FIG. 110.—Bridge over Lake Ponchartrain, La., built of timbers treated with preservative under pressure.

105. Protection of Wood against Fire.—There are two general means of reducing the spread of fire in wooden buildings. One is the use of proper methods of construction, the other is to treat wood so as to make it fire retardant including the installation of automatic sprinklers in large buildings. The education of the public as to the causes and methods of preventing fires is of primary importance in reducing fire losses.

(*a*) *Proper Construction.*—A type of construction known as "mill construction" is being used to a large extent for factory buildings. By "mill construction" is meant that type of building in which the girders and posts are of heavy timbers; the floors at least 3½ inches thick; and the roof at least 2⅝ inches thick. The timbers have smooth, flat surfaces; and hollow spaces in the walls and floors are avoided so that fire cannot spread rapidly from one part of the building to another. No hidden fires can be present in a building of this type. The large beams

and posts burn slowly, just as a whole log burns more slowly than if cut into pieces, and they will endure considerable charring before they fall. In fact a wooden beam or post is considered safer in a fire than an unprotected or poorly protected steel girder or post as explained in the following quotation taken from the recommendations of the National Board of Fire Underwriters.[1]

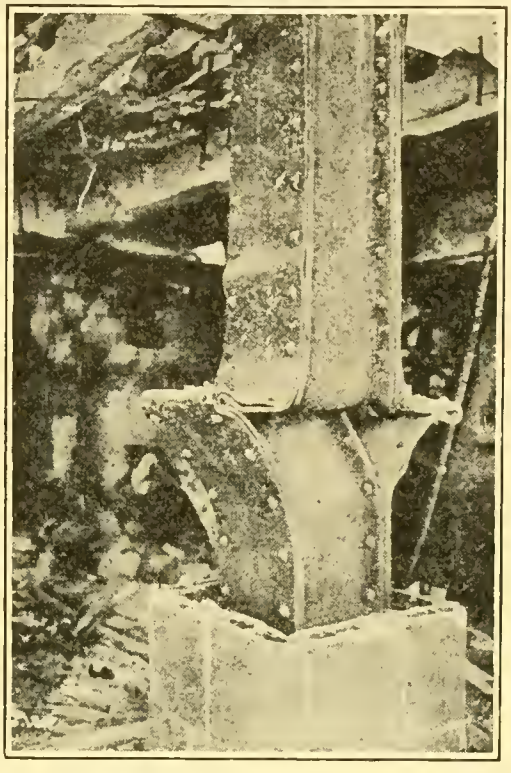

FIG. 111.—Steel column softened by heat and crumpled under load causing much damage during fire although protected by thin layer of hollow tile.

An unprotected steel beam when attacked by fire is not so reliable as a wooden beam. The reason is that steel loses its strength very rapidly when heated in excess of 500 to 600° F., and such temperatures are easily attained in an ordinary fire. On the other hand a wooden beam of large cross-section would burn fiercely over its whole surface, but the actual rate of penetration would be slow; consequently, considerable time would be required for a beam to burn sufficiently to collapse even in a hot fire.

Figure 111 shows how a poorly protected steel column may give way in a fire.

[1] "Dwelling Houses, A Code of Suggestions for Construction and Fire Protection."

In the construction of frame dwelling houses numerous precautions can be taken to make them more fire resistant. For information along this line the reader is referred to the publication from which the preceding quotation is taken. The following quotation from the report of the National Conservation Commission (1909) is also pertinent:

> While the prevailing material of construction—lumber—is largely responsible for the great fire waste of the United States, there is a cause lying back of all this—faulty construction and equipment of buildings. The list of causes of fire is headed by defective chimneys, flues, fireplaces, and heating and lighting apparatus, all of them faults of construction and equipment.

The relative inflammability of different species has little bearing on the selection of wood for buildings. Although some woods ignite more easily than others at low temperatures, at high temperatures such as are usually found in burning buildings all woods ignite in a short time. Rotten wood, however, burns much more readily than sound wood, and adds seriously to the fire hazard of wooden structures both because it ignites more easily and because it already is in a weakened condition.

(*b*) *Fire Retardants.*—There are two general methods of making wood fire resistant: (1) Covering wood with some material which prevents the access of air necessary for combustion, and (2) impregnating the wood with some chemical which gives off a gas when heated, thereby diluting the combustible gases given off by the wood to the extent of making them non-inflammable.

The chief coverings so used for protecting wood against fire are metal, asbestos, concrete or plaster, so-called "fireproof" paints, and even whitewash. A covering of metal is too expensive for most purposes although it is practical for fire doors in which the expansion and buckling of solid metal under high temperatures might be disastrous. A method of spraying molten metal, as copper or aluminum, on wood surfaces where it forms a thin crust has been tried, but because of the brittleness of metal in this form it is not so effective as sheet metal. Covering wood with asbestos in some form is also effective in retarding combustion but is rather expensive.

"Fireproof" paints are of two kinds: (1) Oil paints with a large proportion of non-combustible mineral matter in them,

and (2) those which do not contain oil but instead contain a solution of water glass or glue, or only water for a vehicle. These paints serve to smooth down the rough, fuzzy surface of wood and prevent the free access of air. Oil paints have the disadvantage that they burn more readily than water paints, but on the other hand they are more permanent. Dense coatings of whitewash have considerable fireproofing value, and with the addition of silicate of soda (water glass) are often used. Sodium silicate, borax, and ammonium phosphate fuse when they become hot, thereby covering the wood fiber with a thin film and more effectively preventing the access of oxygen.

Chemicals which give off non-inflammable gases are usually impregnated into the wood. This process requires more extensive apparatus than surface coatings, and involves drying after treatment, but it is more effective, for the surface of wood so treated may be charred off and the layers underneath will still be fire resistant.

In tests on numerous fire retardants at the Forest Products Laboratory[1] the chemicals found most practical for impregnation were ammonium phosphate and ammonium sulphate (separate or in mixture), ammonium chloride, and borax. Results of tests with these chemicals impregnated in noble fir are shown graphically in Fig. 112. The tests were made in a way similar to that used for the untreated woods in Fig. 65; that is, by exposing the woods to various temperatures until ignition took place from a pilot flame which in itself did not heat the wood appreciably but only ignited combustible gases. Ignition in the effectively treated woods consisted of incandescence or glowing accompanied by a small blue flame (probably carbon monoxide), as contrasted with a yellow flame in untreated or insufficiently treated wood, and the time limit for ignition was determined accordingly. The difference alone in the manner of ignition in the treated and untreated woods would make a great difference in the rate at which fire would spread in a building, not considering the longer time required for some of the treated material to ignite. Figure 113 shows the difference, after an inflammability test, between an untreated shingle and a shingle treated with a fire retardant.

[1] See, PRINCE, R. E., "Tests on the Inflammability of Untreated Wood and Wood Treated with Fire-retardant Compounds." *Proc.* of the 1915 Meeting of the National Fire Protection Association.

Sodium carbonate, sodium bicarbonate, and zinc chloride have somewhat of a fire-retardant action, but not sufficient for practical purposes. Chemicals injected into wood to decrease its combustibility are used in the form of water solutions, and, therefore, are also subject to leaching and should not be used for outside work unless the wood is kept well painted with an oil paint.

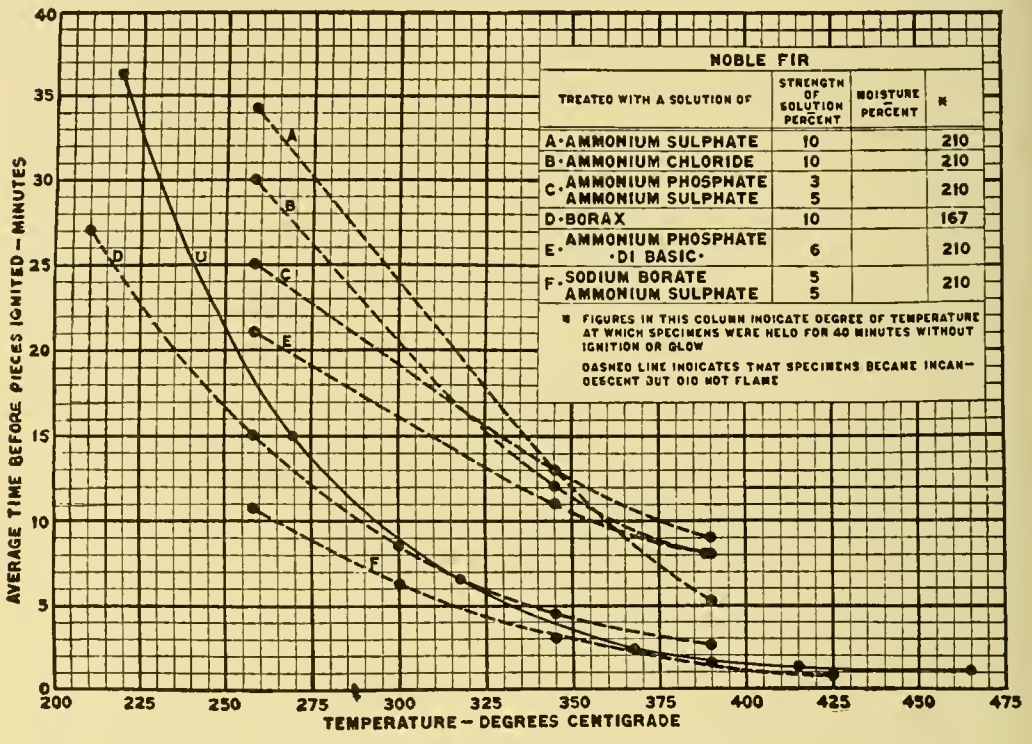
NOBLE FIR
TREATED WITH A SOLUTION OF
STRENGTH OF SOLUTION PERCENT
MOISTURE PERCENT
*
A·AMMONIUM SULPHATE 10 210
B·AMMONIUM CHLORIDE 10 210
C·AMMONIUM PHOSPHATE 3
AMMONIUM SULPHATE 5 210
D·BORAX 10 167
E·AMMONIUM PHOSPHATE ·DI BASIC· 6 210
F·SODIUM BORATE 5
AMMONIUM SULPHATE 5 210
* FIGURES IN THIS COLUMN INDICATE DEGREE OF TEMPERATURE AT WHICH SPECIMENS WERE HELD FOR 40 MINUTES WITHOUT IGNITION OR GLOW
DASHED LINE INDICATES THAT SPECIMENS BECAME INCANDESCENT BUT DID NOT FLAME
AVERAGE TIME BEFORE PIECES IGNITED – MINUTES
TEMPERATURE – DEGREES CENTIGRADE
0 5 10 15 20 25 30 35 40
200 225 250 275 300 325 350 375 400 425 450 475
A B C D E F U

FIG. 112.—Relation of temperature and time of ignition. Curve *U* represents untreated noble fir at 18 per cent moisture. (*Courtesy, Forest Products Laboratory.*)

A fire retardant which will not leach out can be made by first impregnating the wood with a borax solution (sodium borate). When this is dry, the wood is again impregnated with zinc chloride. The sodium and zinc change places forming the insoluble fire-retardant zinc borate, and the soluble sodium chloride (common salt). It has been found that shingles treated by this method and soaked in running water for two weeks still retain their fire-resistant properties.

Factors to be considered besides the effectiveness and cost of fire retardants are their effect on the strength of wood; on subsequent coatings such as paint, varnish, etc.; and whether they have any corrosive action on metal fastenings.

There is no means of rendering wood absolutely fireproof, that is, making it unaffected by heat. All the above-mentioned methods at their best only prevent burning with a flame, or glowing. No matter how wood is treated it will char and become brittle at high temperatures. However, wood properly treated will very effectively retard the progress of a fire, and will usually

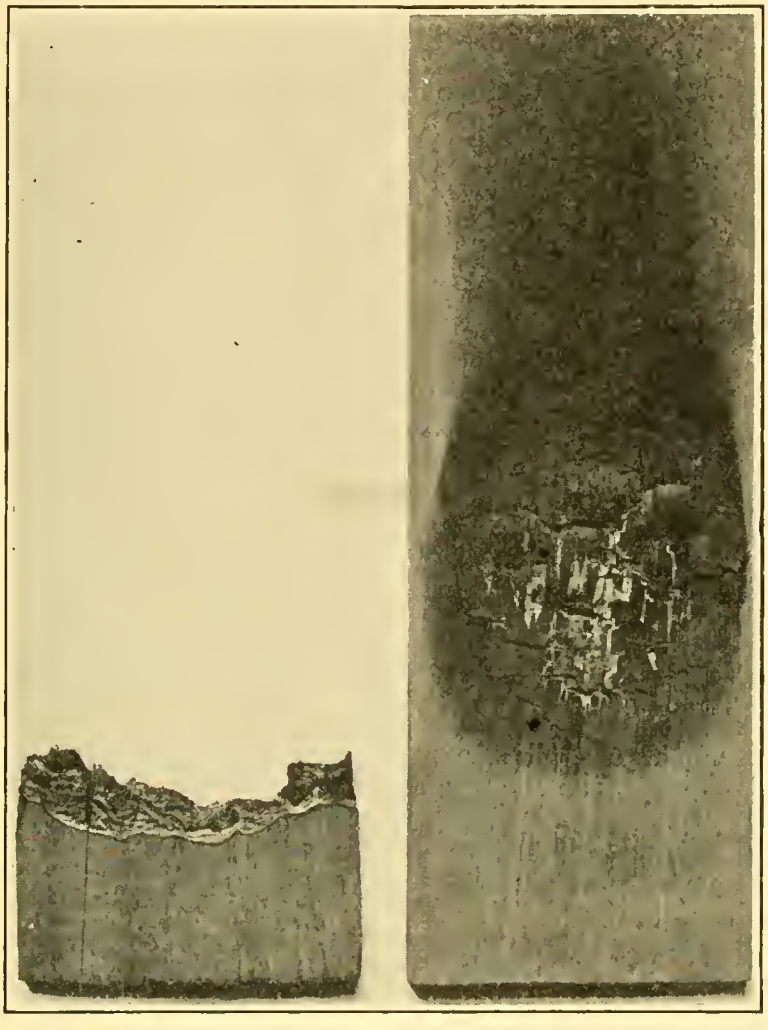

FIG. 113.—Treated and untreated shingles exposed to inflammability test at Forest Products Laboratory. One to left untreated, exposed one minute; one to right treated with zinc borate and exposed twelve minutes.

allow sufficient time for the fire department to extinguish the fire before it attains large proportions.

(*c*) *Educational Methods.*—From eighty-five to ninety per cent of fires in buildings are preventable. They are due either to carelessness or ignorance. The misuse of electrical appliances; carelessness of smokers; indiscretion in the use of gasoline; neg-

lected furnaces and flues; and accumulations of rubbish, especially oily waste, are responsible for a large percentage of fires. The education of the public in the recognition of such hazards through the press, schools, insurance companies, social organizations, and the institution of a "fire protection week" is becoming a very effective means of reducing fire losses in this country.

CHAPTER XI

PRINCIPAL FACTORS GOVERNING THE USE OF WOOD

The uses to which wood is put depend ultimately on its properties as compared with those of other materials, and on its availability. In other words, the service wood gives and the ease with which it may be obtained determine in the long run the purposes for which it is selected and the quantity so used. The cost is often the immediate factor which determines the extent to which an article is used, but the cost, in general, is regulated by the demand and supply.

A knowledge of the properties, supply, and prices of timber and of its substitutes is essential, therefore, in order to understand the various uses of wood.

Other factors, as social and economic conditions, may also affect the demand for wood somewhat. Education of the public in the proper use of wood, as through advertising, increases the demand for lumber, but this is based on directing the attention of the consumer to the usefulness and price of a material. Scientific research may reveal properties hitherto not considered, thereby increasing the demand, or the discovery of substitute materials may cause a reduction in demand.

106. The Properties of Wood.—In choosing a material for construction purposes or for the manufacture of any article the properties of various materials should be considered. For some purposes wood is chosen because it offers certain advantages especially when the price is also considered, for other purposes the advantages of metal, clay products, glass, or stone outweigh those of wood. For certain purposes the advantages of wood are so much in its favor that no other material has yet been found to take its place satisfactorily, for example: railway ties, airplane propellers, airplane frames, canoes, sounding boards, handles of various kinds, gun stocks, house floors, interior finish, household furniture, temporary construction, crates, and large packing boxes.

The following are the principal factors, aside from its abundance, which have made wood the most common building and construction material:

1. It is fairly light, and, therefore, easily handled and transported long distances, especially when seasoned. Timber products are now being shipped from Oregon to New York in considerable quantities.

2. It is easily worked into various shapes. A few simple tools suffice, and little skill is necessary for ordinary woodwork.

3. It is easily fastened together, especially with nails and screws.

4. It holds paint well on account of its porous nature.

5. It is strong for its weight.

"Weight for weight kiln-dry spruce is actually as strong and stiff in compression and bending as fairly good steel, and considerably stronger than cast iron."[1] In tension along the grain kiln-dry birch is from one-fourth to one-half as strong as mild steel of the same cross-section, but it is only about one-tenth as heavy.

6. It transmits heat, sound, and electricity poorly.

7. It expands and contracts little on heating and cooling.

8. It absorbs shocks and vibrations better than other structural materials. Steel is not so good for wagon axles and spokes as wood because it lacks the resilience of wood.

9. It resists rust, acid, and salt water better than most of its substitutes.

10. What defects are present are usually visible on the surface, thus making it possible to reject poor material.

11. It is highly ornamental because of pleasing and varied figure.

12. It floats, as a rule, unless saturated.

13. Its salvage value is high, compared with original cost.

The ease with which wood can be shaped and fastened together, its strength, and its abundance are the chief reasons why it has been the leading structural material since man first used tools. Its low conductivity of heat and its sound-deadening qualities are properties that cannot be easily duplicated in other building materials. In a structure which is subjected to vibrations and jars, as an airplane or wagon, wood is preferred for many parts because it absorbs the vibrations to a large extent, transmitting

[1] Teimann, H. D. "The Strength of Wood as Influenced by Moisture." Forest Service *Circular* 108.

them only feebly to the extreme parts. The capacity of wood to "give" and "come back" quickly when subjected to sudden shocks, a property known as "resiliency," makes wood the material par excellence for spokes, ball bats, and railway ties.

The belief, therefore, that wood is a temporary form of construction because it is cheap, and eventually will be replaced by what are believed to be more efficient materials, is based on inaccurate information concerning wood and its properties. If we were confronted by a real timber famine and had to use other materials, the greater efficiency of wood for many purposes would become apparent. It is highly desirable, therefore, that every effort should be made to promote the cause of forestry so as to maintain a perpetual timber supply.

On the other hand, it must not be overlooked that wood has limitations and disadvantages as compared with other structural materials.

The following factors limit the use of wood:

1. It cannot be drawn out into greater dimensions as can the metals, although gluing overcomes this disadvantage to a certain extent.
2. It is limited in hardness although sufficient strength may be obtained by using proper sizes.
3. It shrinks and swells with changes in moisture content.
4. It burns.
5. It decays. While wood preservation increases the life of timber, it is not considered so permanent a form of construction as steel and stone.
6. It is variable in strength, even in the same species.
7. It splits easily along the grain.

The properties of wood which influence the choice of one species in preference to another are usually one or several of the following: Strength in compression or bending; toughness, or shock-resisting ability; stiffness; hardness; resistance to abrasion; weight; durability; low shrinkage per cent; comparative freedom from warping and checking; workability; suitability for bending; surfacing quality; nailing without splitting; natural beauty; manner of taking paints, stains, varnishes, and enamels; penetrability by liquids; odor; taste; and chemical properties.

Often a combination of properties is sought. The strength together with the durability of yellow pine, Douglas fir, and white oak makes these species very suitable for bridge stringers and

railway ties. The toughness and smooth finishing quality of hickory and ash make them excellent for tool handles. Rock elm is sufficiently tough but will not give so smooth a surface. The softness and comparative freedom from warping of sugar pine and white pine make these species desirable for drawing boards. A combination of strength and good bending qualities make ash one of the most desirable species for bent woodwork. Easy workability and the readiness with which it takes paints, stains, and enamels are the qualities which have given red gum its widespread use. The natural beauty of mahogany together with its low shrinkage per cent and comparative freedom from warping makes it one of the best woods for scientific instruments and other high class woodwork.

In order, therefore, to select the best wood for a particular purpose the requirements that must be met and the properties of the many woods on the market must be understood. As lumber becomes higher priced, as new species are put on the market, and as the substitute materials become more numerous, it will become increasingly advantageous for the manufacturer of wooden products to become thoroughly familiar with the properties of different woods in order to turn out a satisfactory product at a reasonable price. The value of selecting and treating woods properly is shown by the satisfaction wood gives in the construction of airplanes, in which it meets the most exacting demands.

Those properties which readily lend themselves to description or measurement have already been discussed in earlier chapters.

107. Timber Resources of the United States.—That the growing scarcity of the total amount of standing timber of certain species has curtailed their use is well shown in the case of white pine and yellow poplar both of which are unsurpassed in quality for a large variety of purposes. In 1899 the annual cut of white pine amounted to 7,700,000,000 board feet; in 1916 the cut had fallen off to 1,500,000,000 board feet, inclusive of western white pine. For yellow poplar the annual cut was 1,100,000,000 and 350,000,000 board feet for the same years respectively. The decreased cut is due almost entirely to the great reduction in the stand of these species.

Contrary to the general belief, however, no exhaustion of timber in general exists. It is true that forests have been removed from large areas now under cultivation and never again

to be used for growing timber, but statistics show that almost half of the original forest resources of this country are still on the stump. It is estimated that the original standing timber in the United States amounted to 5,200,000,000,000 board feet covering 822,000,000 acres. The ax, fire, and insects have since reduced the stand to 2,215,000,000,000 board feet or 42.6 per cent of the

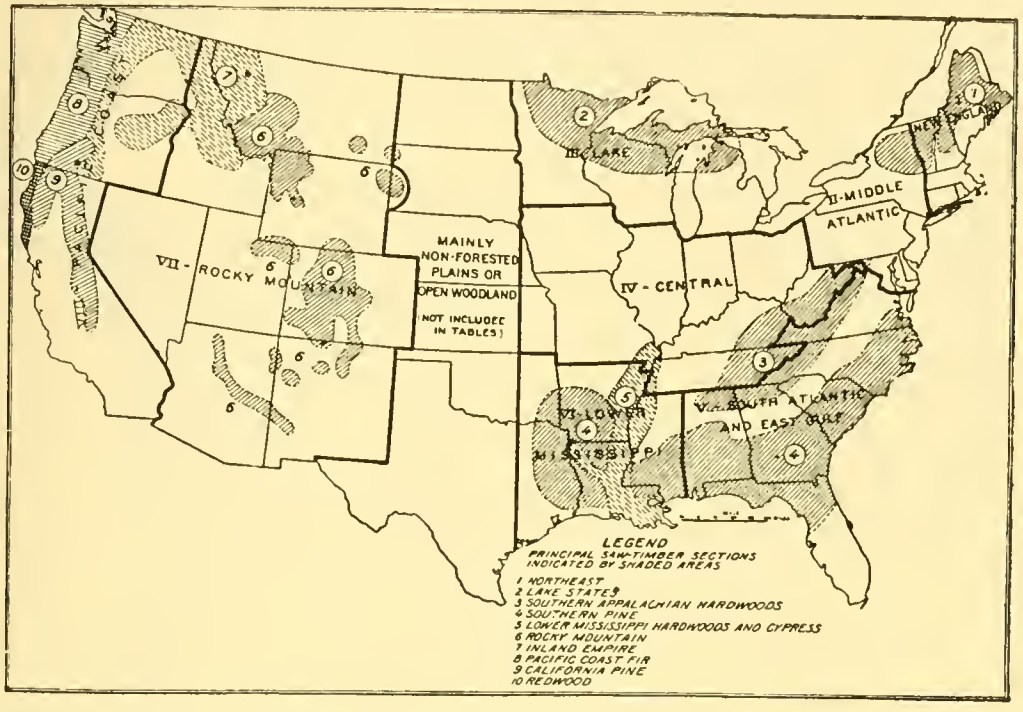

FIG. 114.—Forest regions by state groups and principal saw-timber sections.

REGIONS	TOTAL FOREST AREA (MILLION ACRES)	STAND OF SAW TIMBER (BILLION BD. FT.)
I New England	24.7	49.8
II Middle Atlantic	28.7	44.9
III Lake	57.1	110.1
IV Central	56.7	144.1
V South Atlantic and East Gulf	99.0	221.7
VI Lower Mississippi	78.9	280.2
VII Rocky Mountain	60.8	223.1
VIII Pacific Coast	57.6	1141.0
Total	463.5	2214.9

original, and the area to 463,000,000 acres or 56.3 per cent of the original. The stands and forest areas are shown for each group of states in Fig. 114. From the above statistics it will be noticed that the stumpage has been reduced more than the forest area. This is due to wasteful methods of logging, in which the best timber is removed over large areas leaving what is still a forest but containing only injured, defective, small, and otherwise undesir-

able trees. In fact the virgin tracts of timber left in this country cover only one-sixth of the original forest area. Eventually, if the land is not fit for agriculture, another forest crop may be removed from cut-over areas. But without fire protection and proper management, factors which the lumberman is, as a rule, not able or willing to supply, such forest land is far from efficient.

Our forests are naturally divided into five regions, the Northern Forest, the Central Hardwood Forest, the Southern Forest, the Rocky Mountain Forest, and the Pacific Coast Forest (Fig. 115).

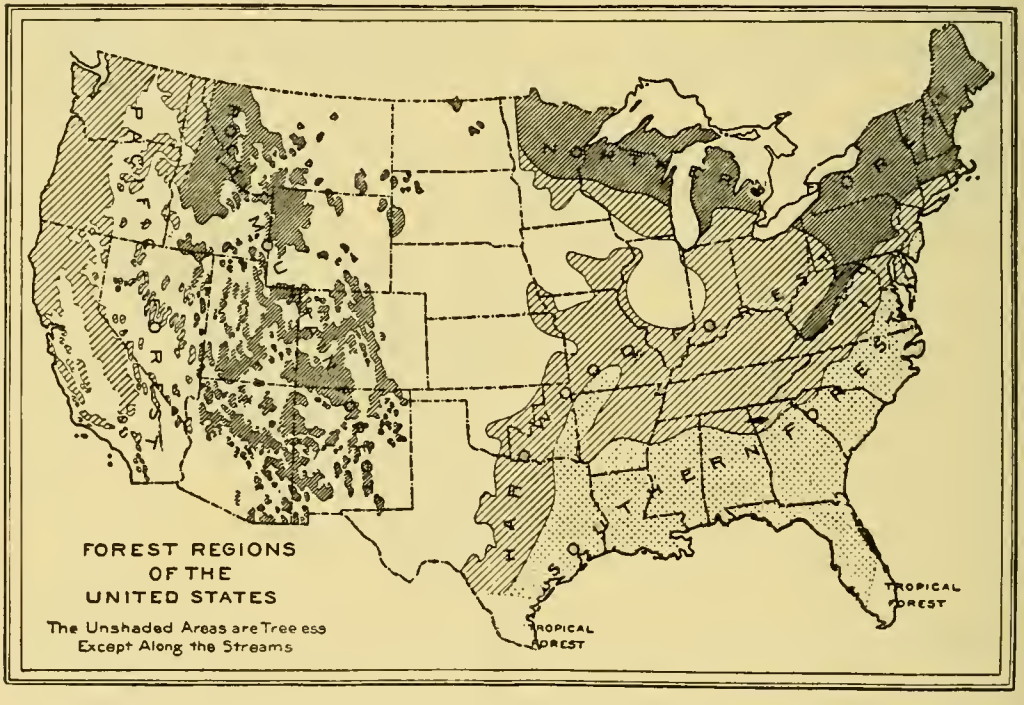

FIG. 115.—Natural forest regions of the United States. (*Courtesy, U. S. Forest Service.*)

The Northern Forest, which includes the Northeastern States, Lake States, and Appalachian Region, was primarily a coniferous forest, with white pine the principal timber. Other important conifers distinctive of this region are Norway and jack pines; hemlock; white, red, and black spruces; balsam fir; northern white cedar; and tamarack. Some hardwoods are found mixed with the conifers throughout, the most important being: sugar, red, and silver maples; sweet and yellow birches; beech; white, rock, and slippery elms; black and white ashes; basswood; chestnut; and some oaks. Of these hardwoods, black ash and yellow birch are distinctly Northern species, while the others are also found farther south.

The pine of this region is confined principally to the poorer sandy soil not very desirable for agriculture. However, the unparalleled quality of the white pine prompted the lumberman to seek it out in places remote from areas coveted by the farmer, so that much cut-over land has remained for many decades without further molestation from the hand of man. The resultant second growth and cull of the original forest have made it profitable in many places for a second lumbering operation to follow the first one.

The Central Hardwood Forest Region unlike the Northern Forest Region covers rich agricultural land lying in the valleys of the Ohio and lower Mississippi Rivers. In the Central States the farmer could not wait for the lumberman to take away even the best timber, but immense piles of oak, maple, poplar, and hickory logs were burned to make room for crops and pasture. No regrets for the denudation of the comparatively level areas of this region are voiced by foresters. It is essentially an agricultural region. On the bottom lands of the lower Mississippi River remain the last large stands of virgin hardwoods.

The principal species found in the Central Hardwood Forest Region are numerous species of oaks; several hickories, including pecan; yellow poplar; basswood; chestnut; sycamore; sugar, red, and silver maples; white, rock, and slippery elms; black walnut; red gum; black gum; sweet birch; cottonwood; hackberry; beech; and white ash. The conifers of this region are negligible from a commercial standpoint.

The Southern Forest, which covers principally the sandy areas of the South Atlantic and Gulf States and portions of adjacent states, abounds in pines. In this region grow the yellow pines with their dense bands of summerwood and high resin content (for this reason also called pitch pines). Longleaf, loblolly, shortleaf, and slash pines are the principal species of southern yellow pine.

On the richer soil, especially along the river bottom and swampy coasts, an abundance of hardwoods is found. The principal species of southern hardwoods are swamp oaks, red gum, sycamore, yellow poplar, cottonwoods, maples, elms, hickories, black gum, tupelo gum, white ash, and beech. Bald cypress is a common deciduous conifer of the swampy areas.

On account of the poor character of much of the soil and the depression which followed the Civil War, agriculture has not

made the progress in the southern states that it has in the central and northern states and, therefore, much timber land still remains.

The great middle section of plains and prairies between the Mississippi River and the Rocky Mountains is treeless except along the streams. This lack of forest growth is due primarily to insufficient rainfall, although it is believed that the prairies have been extended far eastward by repeated fires set by the Indians to improve the buffalo range.

The Rocky Mountain Forest Region is chiefly coniferous, although some hardwoods are found along the rivers and canyons. It contains throughout almost its entire area western yellow pine, Douglas fir, and Engelmann spruce. In the northern portion, that is, in Idaho and Montana, western white pine, western hemlock, western red cedar, larch, and lowland white fir are also important timber trees. Lodgepole pine is very abundant from southern Colorado northward into British Columbia.

The Pacific Coast Forest Region has the distinction of containing the largest trees, the heaviest stands, and the largest remaining areas of virgin timber to be found in this continent. The big tree (*Sequoia washingtoniana*), although not of commercial importance, is remarkable in that it has attained a diameter of 27 feet 8 or 10 feet above the greatly swelled base, a height of 330 feet, and an age of fully 3,000 years. The redwood (*Sequoia sempervirens*), a close relative and even taller tree, is a very important timber species growing along the coast of California. Douglas fir also grows throughout almost the entire wooded area of this region, but attains its largest size in western Oregon and Washington where stands of as much as 250,000 board feet per acre may be found. Western yellow pine (sold as "California white pine" or "western soft pine") is also found throughout this region. Western hemlock, larch, western white pine, western red cedar, Port Orford cedar, Sitka spruce, lowland white fir, and noble fir are principally found in Oregon and Washington. Sugar pine and incense cedar are important trees of California and Oregon.

Figure 114 shows the present stands of timber in the principal producing regions. Originally, the Northeastern States led in the annual production of lumber, but later these were outstripped by the larger operations in the Lake States. It was in the white pine of Michigan and Wisconsin, in fact,

that the lumber industry developed its large-scale operations with extensive machinery duplicated in no other country. In the early nineties, lumbering reached its climax in the Lake States and since has declined quite rapidly in the white pine region.

The South next became the principal lumber-producing region, reaching a maximum production in 1909. Since 1900 lumber production has increased rapidly in the western states. Since 1920 the Pacific Coast and Rocky Mountain states have produced more lumber than the southern pine group. Washington has led all other states in the annual cut of lumber since 1905, except in 1914 when Louisiana led. In 1920 Louisiana lost second place to Oregon but regained it in 1921. Table XXVI shows the rise and fall of the principal states in the production of lumber.

TABLE XXVI.—RELATIVE RANK OF THE EIGHT LEADING STATES IN THE PRODUCTION OF LUMBER SINCE 1850

	1850	1860	1870	1880	1890	1900	1905	1910
1	N. Y.	Pa.	Mich.	Mich.	Mich.	Wis.	Wash.	Wash.
2	Pa.	N. Y.	Pa.	Pa.	Wis.	Mich.	Wis.	La.
3	Me.	Mich.	N. Y.	Wis.	Pa.	Minn.	La.	Miss.
4	Ohio	Me.	Wis.	N. Y.	Minn.	Pa.	Minn.	Oreg.
5	Ind.	Ohio	Ind.	Ind.	Ind.	Wash.	Mich.	Wis.
6	Mich.	Ind.	Me.	Ohio	Wash.	Ark.	Ark.	Tex.
7	Mass.	Wis.	Ohio	Me.	N. Y.	Ohio	Pa.	Ark.
8	Ill.	Cal.	Mo.	Minn.	Ohio	Ind.	Miss.	N. C.

	1915	1916	1917	1918	1919	1920	1921	1922
1	Wash.	Wash.	Wash.	Wash.	Wash.	Wash.	Wash.	Wash.
2	La.	La.	La.	La.	La.	Oreg.	La.	La.
3	Miss.	Miss.	Oreg.	Oreg.	Oreg.	La.	Miss.	Oreg.
4	N. C.	Oreg.	Miss.	Miss	Miss.	Miss.	Oreg.	Miss.
5	Ark.	N. C.	Ark.	Ark.	Ala.	Cal.	Tex.	Cal.
6	Tex.	Tex.	Tex.	Tex.	Ark.	Ark.	Ala.	Tex.
7	Oreg.	Ark.	Ala.	Cal	N. C.	Ala.	Cal.	Ala.
8	Ala.	Ala.	N. C.	Wis.	Tex.	Tex.	Ark.	Ark.

For several decades the annual production of lumber, ties, and sawed timbers has been in the neighborhood of 35 or 40 billion board feet. If to this is added the amount used for hewed ties and timbers, round mine timbers, posts, poles, piling, fence posts, vehicle and handlestock, cooperage stock, pulpwood, wood distillation, veneers, excelsior, and the firewood cut from what would make saw logs, but not the great amount of firewood cut

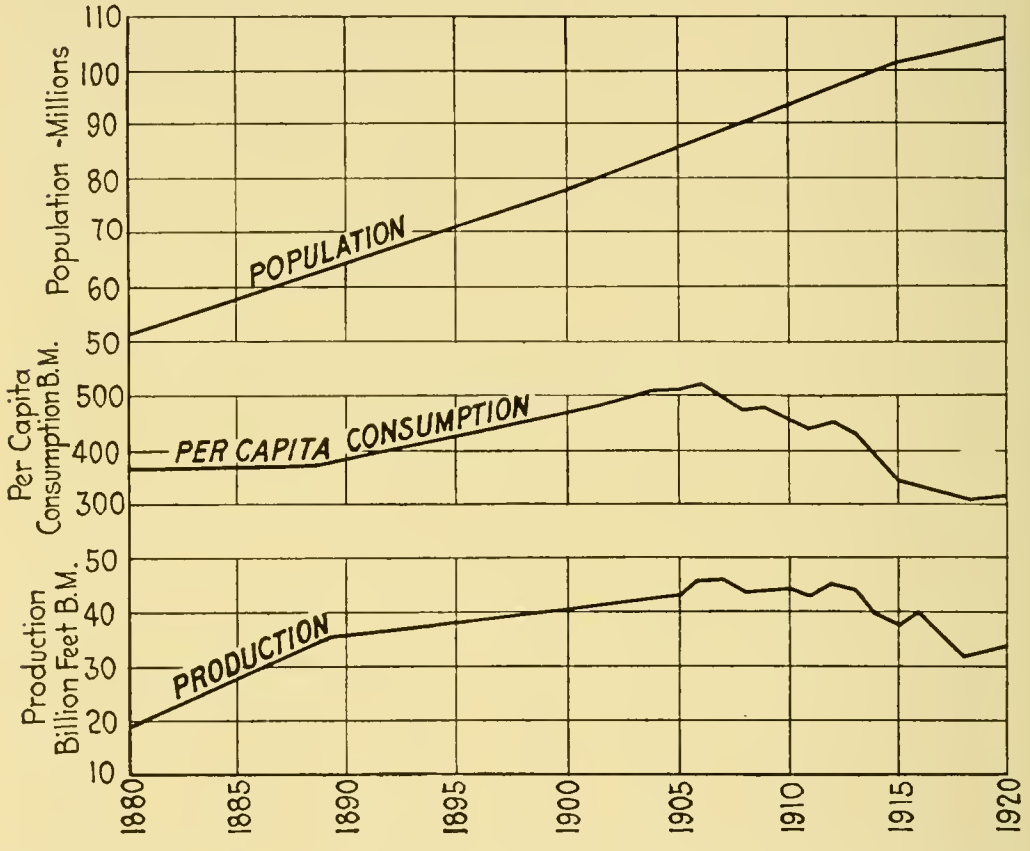

FIG. 116.—Population, per capita consumption, and annual production of lumber in the United States 1880 to 1920.

from less valuable material, it totals to the stupendous sum of fully 52,800,000,000 board feet.[1] The quantity of lumber represented by this figure can be understood better by imagining it in the form of a board walk, 5 feet wide and 2 inches thick but without stringers. Such a walk would contain 10 board feet for every foot of length making enough lumber for 5,280,-

[1] If the fuel wood not accounted for in this figure were converted into board feet and added thereto, the total annual wood consumption in the United States would be expressed approximately as 100 billion board feet.

000,000 feet, or 1,000,000 miles of walk—40 times around the world or 4 times to the moon.

Although the annual production and consumption of lumber have not changed a great deal within the last two or three decades the per capita consumption has decreased considerably since 1906 and 1907, which were the years of maximum production. This is shown graphically in the production curve in Fig. 116.

The question naturally is asked, "How long will our timber supply last?" With an annual consumption of about 52,800,000,000 board feet and a stand of 2,215,000,000,000 board feet, then without additional growth it would last about 42 years. However, many of our cut-over and burned-over areas are again growing timber, although not so rapidly as it is being cut elsewhere. In fact we are cutting our timber about four times as fast as it grows. This means that three-fourths, or 39,600,000,000 board feet, of the annual cut is taken from the capital stock. At this rate our forests would be exhausted in about 56 years. Other factors, however, will come into play which will postpone for many years, let us hope indefinitely, the day when wood shall no longer be available. These factors are:

1. More efficient use of what is cut, including a more extensive use of timber treated with preservatives.
2. Greater importation of woods from the tropics, Siberia, etc.
3. Substitution of other materials for wood.
4. Greater protection of forests from fire.
5. Increasing the annual growth on our forest areas by proper forestry methods.

These things will be brought about by higher lumber prices as timber becomes scarcer. While the total supply of timber is sufficient for several generations without any serious curtailment, the fact remains that timber is becoming more and more difficult to obtain. Logging along streams, once affording easy and inexpensive transportation, is almost obsolete. The timber has been cut away from most of the streams and the lumberman now finds it necessary to go inland and build many miles of logging railroad, often along mountain sides, over canyons, and through swamps. This increases the cost of production and causes a relative scarcity of lumber. The amount used, therefore, will decrease on account of the necessarily higher prices demanded by the lumbermen for their product.

108. Lumber Prices.[1]—The cost of lumber is one of the principal immediate factors which determine the extent to which it is used. As the price o lumber increases, the builder and manufacturer look around for other materials that may be used with greater economy. More care is also taken to avoid waste of any lumber that is used, and more of the lower grades come into demand so that the total amount of timber cut becomes appreciably less as the price increases.

The price of lumber like that of most other commodities has increased considerably during the last 25 years; in fact lumber

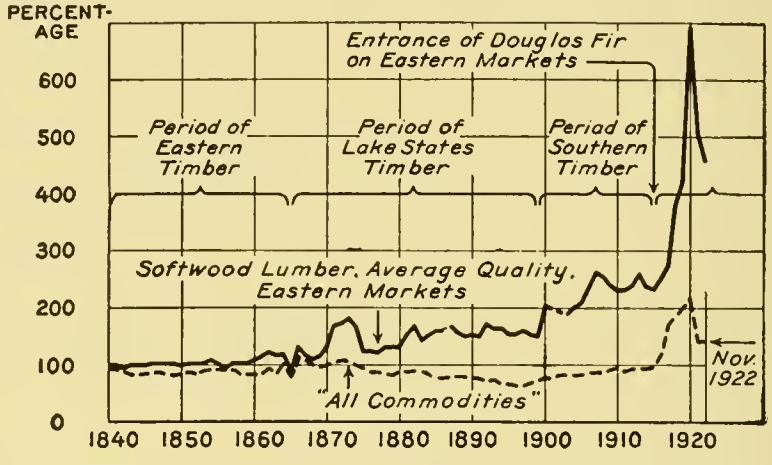

FIG. 117.—Effect of local timber depletion on wholesale prices of soft wood lumber compared with average prices of all commodities. (*From "Timber: Mine or Crop?" United States Department of Agriculture Yearbook*, 1922.)

[1] A detailed discussion of lumber prices may be found in the following:

Report of the Bureau of Corporations, "The Lumber Industry, part IV, Conditions in Production and Wholesale Distribution, Including Wholesale Prices," 1914.

COMPTON, WILSON, "The Organization of the Lumber Industry." Published by the *American Lumbermen*, Chicago, 1916.

THELEN, ROLF, "The Substitution of other Materials for Wood." *Rept.* **117** of the Office of the Secretary of the United States Department of Agriculture, 1917.

GREELEY, W. B., "Some Public and Economic Aspects of the Lumber Industry." *Rept.* **114** of the Office of the Secretary of the United States Department of Agriculture, 1917.

BUTLER, O. M., "The Distribution of Softwood Lumber in the Middle West. Retail Distribution." *Rept.* **116** of the Office of the Secretary of the United States Department of Agriculture, 1918.

Report on Senate Resolution 311, "Timber Depletion, Lumber Prices, Lumber Exports, and Concentration of Timber Ownership" by the Forest Service, 1920.

United States Department of Agriculture Year Book 1922, "Timber: Mine or Crop?"

prices have increased more rapidly than prices of most of its competitors, some of which have actually decreased between 1907 and 1917. Figure 117 shows the trend of lumber prices and all commodities in general since 1840. The values are expressed in percentage with 1820 prices taken as 100, and on a gold standard throughout. The high prices brought about by the World War reached a climax in the early spring of 1920, and then declined rapidly until the summer of 1921 when they began to increase, and it is very probable that lumber prices in general will continue to increase for many years, because timber is still sold at a price less than that for which it can be grown. Only extensive growth of forests, more thorough utilization of by-products, and more systematic methods of merchandising can prevail in keeping down the price of lumber.

The following are the principal factors which have caused lumber prices to soar:

1. Decreasing purchasing power of the dollar. One dollar bought one and one half times as much in 1897 as in 1913 and 2¼ times as much in 1913 as in 1919, although since then the value of the dollar has increased somewhat. This has affected the price of practically all commodities. It has increased the cost of production and distribution from that chargeable to the lumberjack's board to charges for delivery by the retailer.

2. Increase in stumpage prices. In general, stumpage prices have more than quadrupled since 1900. Several factors have contributed to increasing stumpage prices, chief of which is the growing scarcity of available timber. Enormous quantities of timberlands passed from pub ic to private ownership particularly in the 20 years prior to 1908 at what now seem ridiculously low prices. Those opportunities are gone forever, and available timber can now be obtained only as a rule from private holders at an advance in price.

Speculation boosted stumpage prices after government timber lands were no longer readily available. It is said that lumbermen have often made more money by speculation in standing timber than by lumber manufacture.

The conservation movement which in the nineties resulted in the establishment of numerous forest reserves aided materially in emphasizing the growing scarcity of timber and, consequently, increased speculation.

In the East a more or less continuous income can be obtained from forest lands by repeated selective cuttings, and logged-over land can often be disposed of, two factors which tend to keep timber-land prices up to the maximum.

Although rise in stumpage prices is in part responsible for rise in lumber prices, increased returns from lumber manufacture, such as were experienced prior to 1907, in turn tended to boost stumpage prices.

3. Longer hauls, with correspondingly higher freight rates, due to the regions of production moving farther from the centers of consumption, have added to the price the consumer has to pay for lumber. Hemlock and northern pine from the Lake States were at one time brought to the Chicago market at a very moderate freight charge, but these woods because of their relative scarcity are now being replaced to a large extent by southern pine and western species at a very much higher cost for freight.

In 1920 the lumber freight bill on American railways was approximately $230,000,000 and freight charge for water transportation was an additional $20,000,000 making a total $100,000,000 greater than the average freight charges for 1910, 1913, and 1914. The average rate per thousand board feet shipped was $7.30 in 1920 as compared with $3.75 to $3.85 for the three years above mentioned.

As a result of longer hauls the dealer finds it necessary to handle larger quantities and to hold larger stocks. The extra interest charges together with larger profits based on higher costs add to the price the consumer pays for lumber.

4. Cheap water transportation has given way largely to the more expensive transportation by rail, because timber accessible by water was the first to be cut and has practically disappeared.

5. Demands on the lumber retailer in the form of increased service has aided in boosting lumber prices. A few species and a few grades constituted the stock held in the lumber yards of the earlier days. Now, however, northern pine, hemlock, southern pine, western pine, and Douglas fir and redwood from the Pacific Coast, besides numerous hardwoods, can be purchased in most lumber yards of the Middle States. Grades and sizes of various descriptions to meet particular needs are continuously in demand. Prompt delivery, small sales, and extended credits have also had some share in affecting the price of lumber.

6. The education of lumbermen in matters pertaining to their business, made possible largely through the lumber trade journals

and lumber associations, has prompted them to keep lumber prices as high as the market will bear. Modern methods of accounting which expose unprofitable phases of a business tend to boost prices until that phase also becomes profitable.

Lumber prices cannot soar much more without greatly cutting down lumber consumption. While this country will eventually have to yield to a much lower per capita consumption of lumber as virgin timber becomes practically exhausted, and timber must be grown as rapidly as used, for the next generation or two lumbermen will be anxious to forestall as much as possible any decline in the use of their product in order to realize on their investment. This can be done only by keeping down the price of lumber and giving increased service to meet the competition of other materials.

The following factors tend to keep down the price of lumber:

1. The competition of substitute materials. Already wooden forms of construction have given permanent way to steel and concrete in several lines of work. This will continue, and reeds, fibers, clay, and other materials will take the place of wood more or less if lumber prices should continue to go up.

2. Competition among manufacturers of the same kinds of lumber. The financial status of many timber owners is such that they must cut and sell a certain amount of lumber each year in order to meet carrying charges. Taxes alone are often so high as to make it unprofitable to hold mature timber if there is any market for it. These conditions lead to price cutting and sales without adequate profit to a degree not found in normal business enterprises.

3. Competition among manufacturing regions. Manufacturers of hemlock lumber for instance must meet not only the competition of substitutes other than lumber but also that of yellow pine and Douglas fir. Keen rivalry exists between the various producing regions in obtaining and holding lumber trade, especially in the prosperous Middle West which is without timber of its own.

4. Competition of publically owned timber. About one-fifth of all standing timber, exclusive of Alaska, is owned by the Federal government and the various states. This has a stabilizing influence on lumber prices and will be influential especially in preventing any unwarranted rises in prices that might be prompted by monopolistic ownership of private timber lands.

5. The closer utilization of timber. About one-fourth of the forest is left on the land as "useless" material after the logging operation. About one-half is lost in the manufacture and seasoning of the lumber taken out of the woods, so that only about 25 per cent of the wood in a forest is actually used. This is illustrated graphically in Fig. 118. Of course much of this waste could not possibly be used to advantage under present economic

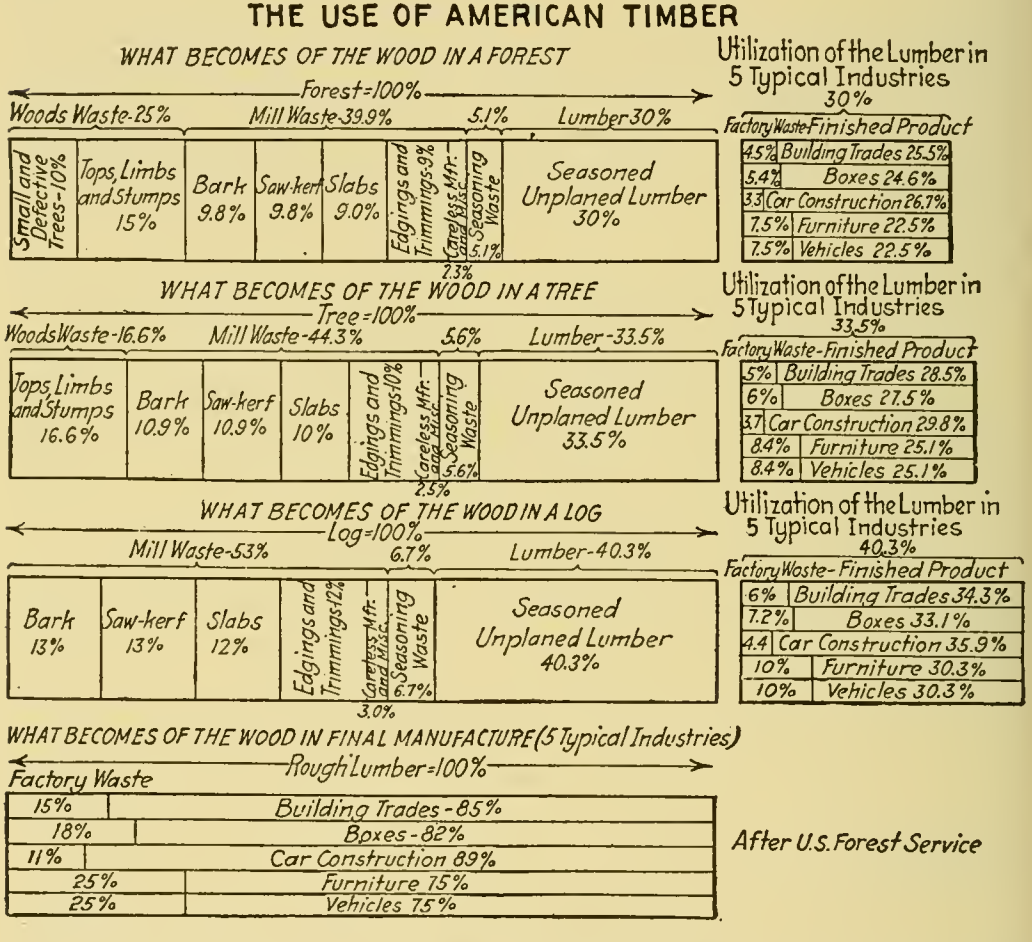

FIG. 118.—Percentages of wood used and wasted from forest, tree, log, and lumber. (*From Forest Service report.*)

conditions, especially in the West because of the lack of diversified wood-using industries and high freight charges to large markets. However, scientific research in finding use for waste products, either in the manufacture of small wooden articles or chemical products, will go a long way in helping the lumberman who is now facing the rising cost of production on the one hand and the stationary or even decreasing price of substitutes on the other hand.

The use of wood, however, will not decrease in the same proportion as the price increases. The fact is, lumber prices have

increased, considerably, since 1897 (Fig. 117), while the total annual lumber cut has not varied much during that time, although the per capita consumption decreased from 516 board feet in 1906 to 300 board feet in 1918. The increase in population has kept up the total consumption.

The outstanding feature is that there does not appear to be any chance for expansion of the lumber industry in this country; in fact the total mill capacity might well be decreased to the advantage of lumbermen in general.

109. Substitute Materials.—Among the factors affecting the amount of wood used annually, the service and cost of substitute materials are foremost. Construction and manufacturing operations continue to increase with increase in the population and prosperity of the country, but, as already stated, the total annual consumption of wood is not increasing and the per capita consumption has decreased materially since 1907. Obviously the use of other materials must be increasing at an even more rapid rate than construction work and the output of manufactured articles in general.

After careful study of available data it has been conservatively estimated that the annual substitution of other materials for wood in places where wood was once used almost exclusively eliminated the use of about 27,715,000,000 board feet of wood in all forms[1] (see Table XXVII).

Much of this substitution is the natural outcome of the progress of civilization and invention; other substitution is made possible by a lack of knowledge concerning the properties of wood, a fact which is made capital of by vendors of substitute materials.

The following are the principal causes responsible for the substitution of other materials for wood:

1. The increasing price of lumber. It has already been pointed out that lumber prices have increased more rapidly than the prices of other materials that may be used in the place of lumber. The initial costs of construction with these materials is not necessarily less, but the materials are more permanent or possess other advantages.

2. Regulations against the use of wood in the congested parts of cities on account of fire risk. The wooden shingle is usually the

[1] THELEN, ROLF, "The Substitution of Other Materials for Wood, Part XI, Study of the Lumber Industry." *Rept.* **117** of the Office of the Secretary of the United States Department of Agriculture, 1917.

TABLE XXVII.—ESTIMATED PRESENT ANNUAL SUBSTITUTION FOR WOOD IN ALL FORMS AND FOR LUMBER

Class of use	Competitors	Substitution	
		For wood in all forms, including lumber, board feet	For lumber, board feet
Building and construction, exclusive of the four following classes.	Steel, brick, concrete, asphalt, etc.	4,050,000,000	4,050,000,000
Fencing	Barbed and woven wire, steel and concrete posts.	3,550,000,000	1,000,000,000
Sidewalks	Cement.	600,000,000	600,000,000
Roofing	Metal, tile, slate, asphalt, asbestos, etc.	1,440,000,000	.....
Lath	Metal lath, wall and plaster boards.	210,000,000	.....
Boxes	Fiber and veneer.	1,500,000,000	1,500,000,000
Railroad cars	Steel.	260,000,000	260,000,000
Furniture	Steel and other metals.	175,000,000	175,000,000
Vehicles	Metal.	30,000,000	30,000,000
Ships	Steel.	150,000,000	150,000,000
Silos	Tile, concrete, brick, steel, etc.	50,000,000	50,000,000
Windmills	Steel.	25,000,000	25,000,000
Cooperage	Steel, veneer, wooden boxes, paper and cotton sacks, etc.	325,000,000	.....
Miscellaneous	.....	350,000,000	250,000,000
Fuel	Coal and oil.	15,000,000,000	.....
Total	.....	27,715,000,000	8,090,000,000

first to be ruled out of downtown districts, next frame construction of any kind, and finally wooden sash, doors, and interior trim in fireproof buildings.

The "safety first" movement together with other factors has been responsible for the growing use of steel railway cars in place of the wooden type.

3. The desire for a more permanent form of construction as a region becomes older and the inhabitants more prosperous. Whenever wood is available it is the chief structural material used by the pioneer because it is easily handled and easily worked. As timber becomes scarcer and other materials come within reach of the financial means of the resident, stone, brick, and concrete take its place.

4. New types of construction, as the skyscraper, large boats, immense dams, and retaining walls, in which only the most permanent material must be used, have replaced smaller structures in the construction of which wood played a large part. However, sight must not be lost of the fact that immense quantities of timber are used for temporary purposes in the building of these large structures.

5. Lack of information concerning the best methods of selecting and utilizing wood. Improperly selected material has caused considerable dissatisfaction with wood. This has been further enhanced by lack of uniformity in grading rules, variations in actual dimensions of timbers from different regions or of different species, and confusion as to common names of useful species.

This lax condition in the lumber industry has been made capital of by steel and cement manufacturers who furnish handbooks giving strength properties, and illustrated literature describing the proper use of their materials.

To what extent this substitution will continue and even increase is a matter of conjecture. Undoubtedly the use of wood for some purposes is practically becoming obsolete, for example, for sidewalks and railway passenger coaches.

All of the above factors, except possibly the fifth, will continue to bear their influence to curtail the use of wood. On the other hand, there are some uses of wood for which no satisfactory substitute has been found. For some purposes timber products are actually replacing other materials, for example, water conduits, pavements, pulp, ethyl alcohol, and textiles.

CHAPTER XII

KINDS AND QUANTITY OF WOOD USED FOR VARIOUS PURPOSES[1]

Of some 500 species of trees which grow naturally in this country, about 50 are of major commercial importance in the production of lumber and 70 are of minor importance. The others are either so small or so scarce that they have no economic significance so far as the production of merchantable wood is concerned. The wood of any of the more important species is used for hundreds of purposes ranging from structural timbers to novelties and toys. Some of the less abundant species have very restricted uses, for example, dogwood for shuttles and red cedar for pencils and clothes chests. The major uses of each kind of wood are fairly well established, although slight changes in the quantity used take place from year to year because of changes in economic conditions and the substitution of other materials or other woods for those heretofore used. Only a general classification of the important uses of the principal kinds of woods will here be made.

110. Principal Uses of Woods.—Table XXVIII[2] gives the classes of products made from wood. The cutting of lumber, which includes sawed timbers, ties, and dimension stock, causes by far the greatest drain on the forests. While a greater quantity of wood, measured in cubic feet, is used for fuel than for lumber, a large part of the fuel is cut from tops, branches, defective trees, and inferior species, and, therefore, the production of firewood does not make so heavy inroads on the forest resources as does the production of materials for which a better quality of wood must be used.

[1] More detailed information on the uses of wood can be found in Brown, Nelson C., "Forest Products, Their Manufacture and Use." John Wiley and Sons, 1919; Kellogg, R. S., and Smith, F.H., "Lumber and Its Uses." U. P. C. Book Co., New York, 1923; and numerous Forest Service bulletins and State wood-using industry reports.

[2] From *Rept.* on Senate Resolution 311, "Timber Depletion, Lumber Prices, Lumber Exports, and Concentration of Timber Ownership" by the Forest Service.

TABLE XXVIII.—TIMBER REMOVED EACH YEAR FROM THE FORESTS OF THE UNITED STATES

Cut	Quantity	Equivalent in lumber which could have been sawed from same trees, board feet
Lumber	40,700,000 M board feet	40,700,000,000
Hewed ties	87,500,000 ties	2,625,000,000
Pulpwood	4,550,000 cords	1,600,000,000
Round mine timbers	250,000,000 cubic feet	750,000,000
Fencing	900,000,000 posts	825,000,000
Poles	4,250,000 poles	255,000,000
Shingles	8,850,000 M shingles	890,000,000
Vehicle stock, handles, woodenware, furniture, etc.	870,000 M board feet	870,000,000
Export logs and hewed timbers.	200,000 M board feet	200,000,000
Veneer logs	650,000 M feet logs	780,000,000
Tight staves	286,000,000 staves	435,000,000
Tight heading	21,000,000 sets	155,000,000
Slack staves	1,010,000,000 staves	305,000,000
Slack heading	61,000,000 sets	225,000,000
Hoops	333,000,000 hoops	90,000,000
Piling	1,500,000 pieces	90,000,000
Lath	2,375,000 M lath	
Distillation	1,550,000 cords	375,000,000
Tanning extract	1,250,000 cords	135,000,000
Excelsior	200,000 cords	75,000,000
Fuel wood	110,000,000 cords	
Total		51,380,000,000
Destroyed by—		
Fire		2,250,000,000
Insects, disease, etc		2,500,000,000
Total		56,130,000,000

NOTE.—Figures on amounts used are in most cases the most recent data available. For lumber the average total cut for the period 1909–1918 was taken (5 prewar and 5 war years). For export logs 1913 figures were used. Fire loss is an estimated average including bad years, such as 1910 and 1919.

The products which are made from wood may be classified, according to the way in which they are prepared for use, into: rough or hewed products, such as fuel, chemical wood, hewed

ties, fence posts, and poles; primary milled products which have been shaped by machinery, for example, sawed timbers, rough lumber, cooperage stock, lath, shingles, and excelsior; and products manufactured from lumber, for example, boxes, interior finish, furniture, agricultural implements, and athletic goods. The kinds and amounts of wood used for fuel and in chemical conversion have a ready been discussed in Chap. VI.

111. Rough and Hewed Products. (*a*) *Railway Ties.*—In the earlier days of the history of the railroads of this country resistance to decay was the only important requisite of a railroad tie, and, therefore, cedar and chestnut were extensively used wherever available. Modern traffic demands a harder tie in most tracks, making it impractical to use cedar and chestnut except on electric lines and steam roads where traffic is light. The commercial development of wood-preservation processes on a large scale, especially by railroad companies, has made possible the use of many woods, which in their natural condition are not durable.

The white oaks, because of their great durability and hardness, are highly desirable for railway ties. About one-third of all ties used belong to the white oak group. Although black locust makes an excellent tie very little of it is available; the locust borer, a grub which works in the stem of young trees, so mutilates the trees that little but crooked, stunted material is obtainable.

The following woods listed approximately in the order of importance are used for ties: white oaks, red oaks, southern pines, Douglas fir, cedars, chestnut, cypress, eastern tamarack, western yellow pine, lodgepole pine, western larch, beech, maples, hemlocks, redwood, red gum, birches, and several miscellaneous species.

The normal demand for railway ties in this country is somewhere between 100,000,000 and 125,000,000 annually. Of these, about 87,000,000 are hewed and the others sawed.

Table XXIX shows the number of ties used and percentage treated at 10-year intervals from 1860 to 1920.

(*b*) *Mine Timbers.*—In many mines it is necessary to reinforce the walls of shafts and gangways in order to keep them from caving in. Timber, because of its cheapness and the ease with which it can be cut into proper shape, is used almost exclusively for this purpose. It sometimes is necessary to replace

TABLE XXIX.—NUMBER OF CROSS-TIES USED ANNUALLY IN THE UNITED STATES, AND THE PERCENTAGE WHICH RECEIVED PRESERVATIVE TREATMENT[a]

Year	Ties used	Per cent treated	Year	Ties used	Per cent treated
1860	10,147,800	From 1860 to 1885	1890	64,168,200	1.01
1870	18,966,600	inclusive.	1900	83,429,400	3.36
1880	35,173,200	Approximately	1910	117,141,300	26.08
		0.1 %.	1920	137,100,000	37.81

[a] From *Rept.* of Proceedings of Meeting of American Wood Preservers' Association, 1921.

FIG. 119.—Use of timber in a mine. Partial caving in caused by decay of props. (*Courtesy, Forest Products Laboratory.*)

the props and other supports a number of times because of the decay which readily sets in under the damp, warm conditions found in mines. Figure 119 shows partial caving in of a mine gangway as a result of decayed props.

The chief properties desired in mine timbers are strength and durability. Proper size and form are also requirements which

should receive attention. If the timbers are to be given a preservative treatment, susceptibility to treatment becomes an important factor in place of durability. Some of these properties are often sacrificed for cheapness.

A great deal of small material can ordinarily be used in mines, and, therefore, regions with scrubby tree growth and logged-over lands will often produce satisfactory mine timber. The most desirable species are black locust, oaks, and chestnut. Less durable woods are often used, so that a list of woods used for mine timbers would include a great variety of species. Approximately 250,000,000 cubic feet of mine timbers are used annually in the United States.

(*c*) *Poles and Piling.*—Two properties, durability and lightness, are very essential for telegraph, telephone, and electric light poles. Straightness, freedom from excessive taper, and a surface upon which climbing irons may easily be used are also desirable. Cedar and chestnut possess these properties to a remarkable degree. About 4,250,000 electric wire poles are used annually, over half of which are northern white cedar and western red cedar.

According to statistics,[1] 4,077,964 poles of all kinds were purchased in 1915. The number of each species or group of species is given in Table XXX.

TABLE XXX.—POLES PURCHASED IN 1915 ACCORDING TO KINDS OF WOOD

Wood	Number of poles	Wood	Number of poles
Northern white cedar	1,747,210	Southern white cedar	89,244
Chestnut	651,643	Cypress	67,644
Western red cedar	567,770	Red oaks	21,643
Pines	546,233	All other kinds	91,233
White oaks	177,799		
Red cedar (pencil cedar)	117,545	All kinds	4,077,964

Pile timber should be straight, with as little taper as possible, strong and fairly durable or susceptible to preservative treatment. Deterioration takes place by decay at the water line; or, in

[1] MCCREIGHT, ARTHUR C., "Poles Purchased in 1915." United States Department of Agriculture *Bull.* **519.**

salt water, by marine borers which work below the water line. In certain sections the borers are far more injurious than decay.

The woods most commonly used for piling are tamarack and Norway pine in the Lake States. Southern yellow pines and oaks are used on the Eastern and Southern Coasts, and western yellow pine and Douglas fir on the Pacific Coast.

(*d*) *Fence Posts.*—For fence posts, durability is the chief requirement, although lightness and not much taper are also desirable. Northern white cedar and western red cedar possess all of these properties to a greater extent than other common species, and, therefore, are usually preferred for fence posts when available. Other woods commonly used are white oaks, cypress, red cedar, southern white cedar, redwood, chestnut, and yellow pines. When given a butt treatment with preservatives, many other species can be used to advantage. Approximately 900,000,000 posts are used each year in this country.

112. Primary Milled Products. (*a*) *Structural Timbers.*—By structural timbers are meant all timbers in which strength is the controlling element in their selection and use. This includes all forms of framing for buildings, such as posts, sills, girders, joists, and studding; bridge timbers; ship timbers; mine timbers; car framing; cross-arms for poles; and dimension stuff for other heavy construction work. The principal requirement for such purposes is that the timber must be sufficiently strong. Where resistance to decay is also essential this can be obtained by selecting durable species or by giving the wood a preservative treatment.

Conifers are used for structural material to a greater extent than hardwoods because they are abundant; they can be procured in large sizes, in comparatively straight pieces and with little taper; they are easily worked; they are lighter than the hardwoods as a class; they do not check and twist so badly in seasoning; and, when used as beams, they do not sag so readily as hardwoods.

The principal species used for structural timbers are the Southern yellow pines, namely, longleaf, shortleaf, loblolly, and slash pine; Douglas fir; cypress; western hemlock; western larch; redwood; western yellow pine; Norway pine; tamarack; red and white spruces; eastern hemlock; and the oaks of which there are about twenty species of commercial importance.

(*b*) *Lumber.*—About 40 per cent of the annual sawmill output of lumber and dimension stuff is disposed of without remanu-

facture. Of this, about one-fifth is normally exported, while the rest is used in general building and rough construction. The remaining 60 per cent of the lumber cut is used by the wood-working industries.

Lumber used without remanufacture includes wood for sheathing, roofing, sub-floors, fencing, outbuildings, walks, and many other forms of construction. The principal species used for these purposes are southern yellow pine, western yellow pine, Norway pine, white pine, Douglas fir, eastern and western hemlocks, cypress, spruce, and some of the lower grades of hardwoods. The chief requirements of material for this purpose are cheapness, easy workability, and lightness. The conifers possess these qualities to a higher degree than do the hardwoods.

(*c*) *Paving Blocks.*—The use of wood for paving has grown rapidly with the development of wood preservation. Wood blocks are used chiefly for paving streets, but are also filling a

FIG. 120.—Street of southern city paved with creosoted wood blocks. (*Courtesy, Forest Products Laboratory.*)

demand for paving floors in factories, warehouses, docks, wharves, yards, and stables. Figure 120 shows a street paved with wood blocks.

The modern creosoted rectangular block when properly laid has certain very desirable features as a pavement. It is easy on the feet of both man and animal; it is comparatively noiseless; when used for factory floors, it reduces damage to sharp-edged tools and fragile parts when dropped; the creosote oil, with which the paving blocks are usually heavily impregnated to prevent decay, lays the dust and because of its antiseptic properties

produces a sanitary pavement; and the pavement is easily repaired.

The proper method of laying a wood block pavement is to provide a solid concrete foundation having the contour and grade of the street when finished. The thickness of the foundation depends upon the character of the traffic. On this foundation is put a cushion of sand not over 1 inch in thickness, or cement mortar dampened just enough to set the cement but not enough to cause it to flow. The blocks, with the fibers in a vertical position, are set on this cushion in rows forming an angle with the curb. An expansion joint of about 1 inch is left along the curbs. After the blocks are rolled to obtain a smooth surface, the joints between the blocks are filled with a hot bituminous filler. The surface is then completely covered with a layer of thin, dry sand.

Wood blocks are set on end because the end surface is harder than the sides, and in this position the fibers do not scurf off so easily as when laid flat. In this position the resistance to wear is surprising. Data collected on the durability of a test pavement in Minneapolis on one of the busiest streets show a wear of about $\frac{1}{32}$ inch per year. The number of wood blocks treated with preservatives fluctuates considerably from year to year. For the 10-year period from 1912 to 1921 inclusive, an average of 7,200,000 cubic feet of paving blocks were treated annually. Southern yellow pine ranks first in importance for paving blocks. Other species used are Douglas fir, tamarack, Norway pine, western larch, and sugar maple.

The chief properties demanded in paving blocks are resistance to wear, freedom from defects, adaptability to treatment, and ability to hold their shape after being in place, as well as original low cost.

(*d*) *Lath.*—Laths are commonly cut into 4-foot lengths and sold 50 or 100 in a bundle. They are cut mostly from slabs and other waste material. The chief requirements of laths are comparative freedom from warping and staining and sufficient softness so that they can be easily cut with a hatchet. Coniferous woods are the principal ones used, but some of softer hardwoods are also manufactured into laths to some extent. The following are the principal species used: white pine, Norway pine, Douglas fir, hemlock, yellow pines, spruces, cypress, and a number of miscellaneous species.

Between 2¼ and 3 million laths are used each year in this country.

(*e*) *Shingles.*—The chief requirements of wood for shingles are durability, comparative freedom from splitting in nailing, and freedom from warping. About 8½ billion shingles are used annually in the United States. The standard shingle is 4 inches wide. Shingles usually are put up in packages of 200 or 250.

By far the larger part of all the shingles manufactured are of cedar, the western red cedar and northern white cedar being the principal species. Other species used are: Cypress; Douglas fir; redwood; yellow, Norway, and white pines; hemlock; and chestnut.

(*f*) *Veneers.*—Veneer is a thin piece of wood cut by veneer-making machinery. It usually is less than ½ inch thick, although there is no standard thickness below which a piece is called veneer and above which it is called a board. Veneer is used either in single thicknesses or several sheets are glued together with the grain crossed, or it is used to cover thicker, and usually inferior, lumber.

Veneer is either cut with a saw, much like ordinary lumber, or it is cut into thin sheets with a knife. By the latter method the wood is either cut into thin straight slices or it is "peeled" off in a continuous layer from a rotating log. The first is called sliced veneer and the second rotary veneer. For both kinds the wood usually is first steamed or boiled for several hours (oak is boiled up to 48 hours) to soften it. Cottonwood, yellow poplar, basswood, Port Orford cedar, and Sitka spruce may be cut without this preliminary treatment.

Sawed veneer is cut with a circular saw of a special pattern. The saw is very thin at the edge, about $\frac{1}{20}$ inch, and gradually becomes thicker toward the center on one side, giving it the shape of a plano-convex lens. The thin edge is necessary in order to produce a thin saw cut, while the thicker center is necessary to give the saw strength and rigidity. The flat side of the saw faces the log or flitch to be cut. Although the other side springs the veneer as it is cut, this causes no trouble in cutting thin sheets. For this method it is not necessary to soak or heat the wood before cutting. It can be cut radially or in any other way as in slicing veneer. On the other hand, the veneer cannot be cut to the extreme thinness which can be obtained by the slicing or rotary method. An advantage of sawed veneer is that both

sides are equally satisfactory for faces of panels, whereas in veneer cut with a knife the side next to the knife becomes cracked because the veneer is bent abruptly away from the bolt or flitch in cutting. One-twentieth of an inch is about as thin as it is practical to saw veneer.

Sliced veneer is made by firmly clamping a flitch in a heavy machine. The wood is then moved up and down with a diagonal stroke before a heavy knife which recedes slightly on the upward stroke and then moves forward a certain distance so as to take

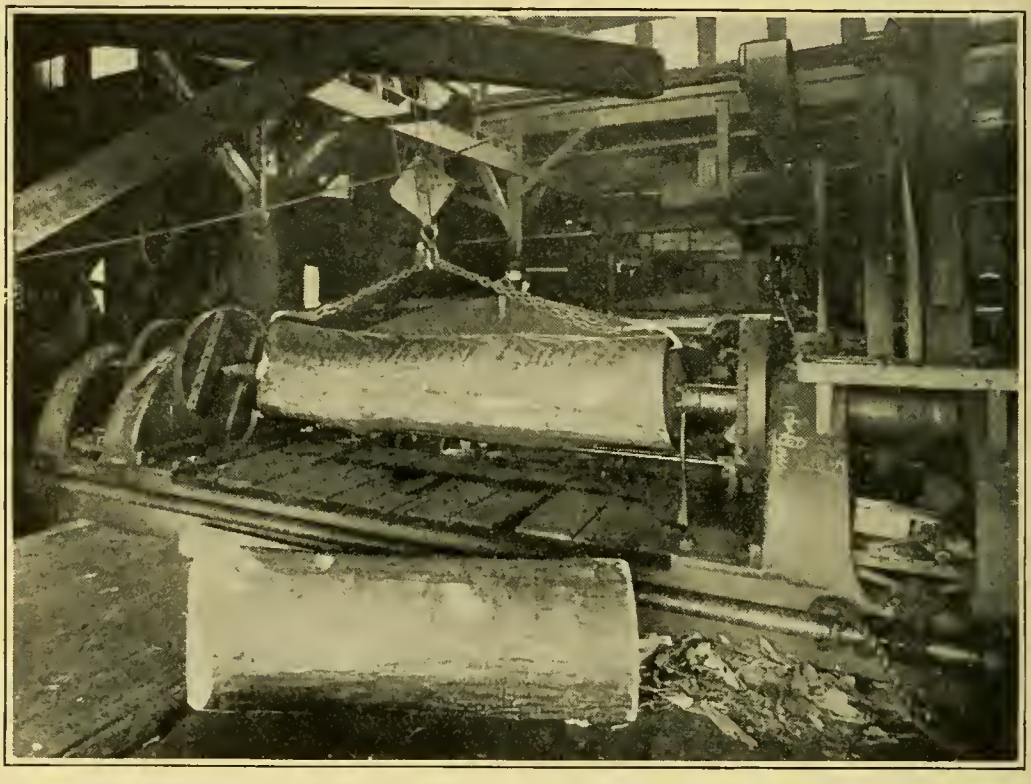

FIG. 121.—Rotary veneer machine. Looking toward the front of the machine showing peeled log set in machine ready for cutting. The log is revolved against a knife which pares off a continuous sheet of veneer. (*Photograph by American Walnut Manufacturers' Association, Chicago.*)

a slice off the flitch on the downward stroke. This method is used chiefly where radially cut veneer is desired and on stumps and crotches, which are cut for their beautiful figure. A considerable quantity of quartered oak is cut in this way. The width of the sheets cut can be no wider than the flitch, but very thin sheets may be secured in this manner. Sheets as thin as $\frac{1}{120}$ inch and even thinner have been cut by this method.

Rotary veneer is made by turning a bolt in a large lathe in which a knife is automatically pressed against the wood so as

to peel off a continuous sheet corresponding in width to the length of the bolt. This sheet of veneer is immediately cut up into suitable sizes, or at least severed at places where serious defects occur. The thickness of veneer cut in this way varies from $\frac{1}{120}$ to $\frac{7}{16}$ inch. A rotary veneer machine is illustrated in Fig. 121.

Since the bolt must be firmly held in place in the lathe by chucks at the ends it can be turned down only to a limited diameter, leaving a core which ranges in diameter from 6 to 12 inches. This core is waste as far as making veneer is concerned. It may be sawed up into crating, box boards, lumber, or used as fuel, pulpwood, or for rollers. The larger the bolt the less the percentage of waste in cores.

The advantages of cutting veneer by the rotary method are that large pieces may be obtained and the work is done quickly. The fact that only flat-grained surfaces may be obtained is a disadvantage in the case of woods that are more beautiful when cut radially. By far the greater portion of veneers is cut by this method.

About 650,000,000 board feet, log scale, of timber are converted into veneer annually, including practically all native commercial woods and some foreign species. Red gum is the principal species used. Next in quantity cut is yellow pine, much of which is worked up into berry boxes and vegetable crates. Cottonwood is easily manufactured into veneer. The sides, tops, and bottoms of egg cases and cracker boxes are made principally of cottonwood. Elm is used extensively for cheese boxes. Excepting yellow pine, comparatively little veneer is made from coniferous timber.

The cutting of veneer was first practiced on high-priced woods used for ornamental purposes, but now veneer is used for a great many other purposes, such as, boxes, crates, barrels, fruit baskets, airplanes, canoes, and other articles in which strength and lightness are essential. For ornamental purposes the veneer is usually glued on inferior lumber of the desired thickness called the core. Light woods, such as white pine and chestnut, are excellent for core stock since they do not shrink, swell, and warp so much as the harder woods, and are easier to handle. Doors and furniture are often made up in this way. In fact, properly veneered material often is more satisfactory than a solid piece of the same thickness and of the species used for the surfaces. For example,

a panel with birch or oak faces and a white pine or chestnut core will keep its shape better than a solid birch or oak board of the same thickness.

Plywood consists of three or more sheets of veneer glued together with the grain of each piece at right angles to that of the piece next to it. There must always be an odd number of pieces so as to produce symmetrical construction, thereby reducing warping to the minimum.

In plywood the bending strength, stiffness, and shrinkage are more nearly equal along and across the grain of the faces than in a single board of the same thickness. If the plywood is composed of about 15 layers, or if the middle layer of three-ply stock is seven-tenths the total thickness of the panel, the bending strength in both directions is about equal. Another advantage of plywood is that it does not split and check so easily as a single board of the same thickness. By gluing up panels, large sizes and curved surfaces may be obtained which find use in the manufacture of furniture, pianos, airplanes, and canoes.

(*g*) *Excelsior.*—The name "excelsior" for this now common wood product is said to have been used first in an advertisement of an upholstery firm which used this material in place of hair in cushions and mattresses. The name was selected by a member of the firm after having heard the original reading of Longfellow's poem "Excelsior." It is still used for filling cheap mattresses and upholstered furniture, for packing articles which are easily injured, and in color schemes for displaying goods. Various grades of coarse and fine excelsior are made to meet certain requirements.

Woods used for excelsior should be soft, white, and without unpleasant odor. The product must be elastic and tough. Basswood meets these requirements and produces the best grades. Cottonwood and aspen are next in desirability and are used even more than basswood because they are cheaper. The other principal woods used are yellow pine, yellow poplar, white pine, willow, and tamarack.

In round numbers 200,000 cords of wood are cut into excelsior annually in the United States.

113. Manufactured Products.—Only a few of the many products made from wood are discussed here. These are mentioned to illustrate the diverse requirements and uses of wood rather than because of their importance.

(*a*) *From Lumber.*—About 24,500,000,000 board feet of all lumber cut, or slightly over 60 per cent, is remanufactured into wooden products of many different kinds. Planing mills consume about 13,500,000,000 board feet of this in the manufacture of sash, doors, blinds, moulding, flooring, casing, ceiling, partition, siding, and general millwork. Yellow pine, white pine, and Douglas fir are the principal species used, but many other woods, including high-priced foreign woods, are also used in millwork.

The manufacture of boxes and crates is next in the demand on lumber. The use of wood for this purpose is discussed later in this chapter.

Table XXXI gives the principal uses of the important species of wood worked up by the wood-using industries of this country. For a clearer understanding of this table the following quotation is taken from United States Department of Agriculture *Bull.* **605,** "Lumber Used in the Manufacture of Wooden Products" by J. C. Nellis, from which this table also is taken:

The scope of the statistics for the industries with titles that are not entirely descriptive is as follows: Planing-mill products cover standard patterns such as flooring, ceiling, and siding, made in large quantities by planing mills in lumber-producing regions, while sash, doors, blinds, and millwork usually are made in millwork plants in the consuming regions. However, considerable quantities of doors and door stock are made in the Pacific Coast States. Boxes and crates cover all kinds of packing boxes and crates made of lumber or veneer, and also fruit and vegetable packages and baskets. Car construction covers wooden construction in all types of railroad and electric cars, as well as in locomotives and mine cars. Furniture includes household and office furniture, except chairs, kitchen furniture, and fixtures in business buildings. Vehicles take in horse vehicles, automobiles, bicycles, pushcarts, and wheelbarrows. Woodenware and novelties embrace a thousand or more articles, such as kitchen utensils, wooden dishes, butter and cheese packages, measures, pails, wooden novelties of all kinds, ladders, and supplies for dairymen, poulterers, and apiarists. Fixtures are such as show cases, counters, bars, and lodge and church furnishings. Shade and map rollers include also curtain and rug poles and Venetian blinds. Machine construction means wooden construction in machinery of all kinds. Shoe lasts, pegs, and shanks are boot and shoe findings. Four-sevenths of the wood used for professional and scientific instruments went for pencils, the rest for artists', photographers', and draftsmen's instruments, rules, and scientific apparatus. Billiard and pool tables, as well as gymnasium goods and all outdoor sporting goods, come under sporting and athletic goods. Mine equipment includes ventilating appa-

TABLE XXXI.—QUANTITY OF EACH KIND OF WOOD USED ANNU-

Industry	Kind of wood			
	Total, feet b. m.	Yellow pine, feet b. m.	White pine, feet b. m.	Douglas fir, feet b. m.
All industries	24,576,556,564	8,610,685,624	3,112,698,017	2,273,788,484
Planing-mill products, sash, doors, blinds, and general millwork	13,428,862,066	6,447,780,805	1,543,345,756	1,991,177,352
Boxes and crates	4,550,016,430	1,044,993,123	1,131,969,940	7,349,840
Car construction	1,262,090,371	678,114,162	75,382,166	86,544,784
Furniture	944,677,807	18,926,400	9,332,808	11,387,790
Vehicles and vehicle parts	739,144,483	31,205,478	1,675,277	930,610
Woodenware, novelties, and dairymen's, poulterers', and apiarists' supplies	405,286,436	18,566,406	47,744,797	2,005,175
Agricultural implements	321,239,336	98,453,396	8,243,440	2,537,250
Chairs and chair stock	289,795,560	20,000	815,068	65,000
Handles	280,234,571	67,000	25,500	247,200
Musical instruments	260,195,026	2,107,994	9,394,820	480,400
Tanks and silos	225,619,686	41,291,700	17,007,600	89,705,322
Ship and boat building	199,598,228	65,698,652	14,256,006	44,342,081
Fixtures	187,132,848	11,612,365	4,864,150	5,512,310
Caskets and coffins	153,394,557	11,970,650	33,170,942	6,000
Refrigerators and kitchen cabinets	137,616,266	7,872,931	8,613,186	543,600
Matches and toothpicks	85,442,111	.....	73,059,611	.....
Laundry appliances	79,502,040	1,397,000	3,026,870	184,500
Shade and map rollers	79,291,575	1,150,000	61,450,000	3,000,000
Paving material and conduits	76,067,000	65,092,000	1,850,000	3,500,000
Trunks and valises	74,667,997	15,277,990	7,299,500	.....
Machine construction	69,459,430	22,461,088	5,405,405	985,100
Boot and shoe findings	66,240,200	.....	.....	.....
Picture frames and molding	65,477,783	5,498,000	5,812,300	6,000
Shuttles, spools, and bobbins	65,148,190	.....	130,000	.....
Tobacco boxes	64,127,476	.....	199,425	.....
Sewing machines	59,946,527	65,000	.....	.....
Pumps and wood pipe	55,826,938	373,230	12,524,000	21,351,480
Pulleys and conveyors	35,862,900	250,000	285,000	129,000
Professional and scientific instruments	35,070,928	46,600	601,670	30,000
Toys	28,926,552	.....	2,367,131	.....
Gates and fencing	27,450,540	6,765,000	3,883,500	805,000
Sporting and athletic goods	25,191,907	943,000	805,300	85,000
Patterns and flasks	24,299,403	1,951,447	17,854,635	54,090
Bungs and faucets	21,112,342	.....	287,000	.....
Plumbers' woodwork	20,313,450	262,250	786,500	.....
Electrical machinery and apparatus	18,188,910	1,264,900	3,022,700	138,000
Mine equipment	16,987,697	1,263,000	239,000	.....
Brushes	12,878,986	.....	75,000	.....
Dowels	11,980,500	.....	25,000	.....
Elevators	10,018,680	3,622,868	1,692,450	415,200
Saddles and harness	9,218,000	.....	10,000	130,500
Playground equipment	9,064,812	1,448,012	42,000	1,000
Butchers' blocks and skewers	8,197,050	.....	200,000	.....
Clocks	7,894,249	926,571	476,064	.....
Signs and supplies	6,888,366	428,856	3,266,950	36,000
Printing material	5,324,794	337,000	11,550	.....
Weighing apparatus	5,021,550	1,180,750	168,000	102,900
Whips, canes, and umbrella sticks	4,946,880	.....	.....	.....
Brooms and carpet sweepers	2,277,334	.....	.....	.....
Firearms	2,093,901	.....	.....	.....
Artificial limbs	687,080	.....	.....	.....
Tobacco pipes	489,515	.....	.....	.....
Airplanes	74,300	.....	.....	.....

ALLY IN THE MANUFACTURE OF WOODEN PRODUCTS—*Continued*

Kind of wood								
Oak, feet b. m.	Maple, feet b. m.	Spruce, feet b. m.	Red gum, feet b. m.	Hemlock, feet b. m.	Yellow poplar, feet b. m.	Cypress, feet b. m.	Western yellow pine, feet b. m.	Birch, feet b. m.
1,983,584,491	919,420,274	805,050,195	797,343,658	708,752,769	680,936,848	668,353,342	563,816,810	481,293,680
501,367,772	317,634,231	350,528,295	121,366,583	442,050,165	236,047,697	508,728,575	264,920,778	133,867,989
56,362,111	96,831,648	335,935,643	402,121,640	203,526,091	165,416,737	38,962,895	288,291,927	90,787,900
305,276,814	5,789,298	8,799,060	1,035,640	12,455,379	32,439,064	1,676,400	4,242,500	5,830,429
431,053,289	87,571,456	2,270,500	102,237,867	7,053,446	53,374,580	3,477,800	1,806,985	54,677,450
212,918,361	35,863,267	835,650	26,650,314	448,678	48,665,960	1,320,951	182,300	14,227,125
7,716,860	38,255,880	28,591,148	8,358,296	2,136,522	7,278,889	8,693,450	262,500	29,547,890
69,346,130	48,319,210	2,623,500	11,976,000	1,257,400	12,412,300	2,682,000	219,000	4,704,000
135,269,118	47,264,747	10,000	8,790,280	216,000	1,140,000	.....	30,000	30,114,332
12,458,472	41,238,446	18,000	6,654,300	500,000	211,900	122,000	.....	9,908,250
20,638,480	45,482,775	29,144,150	9,243,825	615,600	40,371,925	70,000	.....	12,349,055
5,042,401	200,000	10,233,500	1,085,000	1,777,000	240,000	35,408,575	127,000	
32,382,311	1,014,167	7,783,980	164,000	4,745,775	448,077	5,014,741	518,500	1,055,167
62,681,744	20,701,026	2,016,816	5,491,170	473,300	14,574,881	3,364,550	961,720	15,255,129
7,544,255	110,000	1,700,000	7,010,520	1,985,000	9,640,860	19,157,633	543,500	191,000
31,351,521	6,375,242	5,555,690	13,483,400	6,934,872	5,985,729	1,700,500	50,000	3,628,106
.....	1,200,000	750,000	.....	.....	500,000	.....	.....	3,575,000
427,500	14,219,000	2,301,000	3,395,000	1,300,000	1,026,200	15,321,300	5,000	3,876,500
294,000	879,925	7,063,000	2,065,200	.....	326,000	20,000	.....	93,000
4,500	5,047,000	1,759,850	1,783,005	7,000,000	2,988,500	1,275,000	361,000	71,500
8,295,864	3,597,981	729,775	206,500	3,268,191	2,208,577	15,868,405	2,000	470,406
3,000	54,050,000	.....	.....	.....	190,000	.....	.....	7,483,000
16,043,423	309,150	325,000	7,675,040	.....	2,158,814	451,000	.....	3,133,700
39,000	13,531,450	.....	270,000	.....	701,000	.....	.....	33,192,000
403,200	96,450	.....	6,898,270	.....	7,358,919	1,559,027		
19,106,250	324,148	.....	20,774,280	.....	8,039,244	.....	.....	206,000
565,800	1,706,000	.....	3,089,628	.....	1,974,000	2,055,000	.....	55,500
7,343,500	2,436,000	177,000	19,677,500	200,000	400,000	3,000	5,000	745,000
372,100	4,425,167	16,000	75,500	.....	1,001,400	23,000	8,000	1,062,050
1,444,057	3,964,400	1,300	523,000	241,000	882,000	150,000	.....	3,123,950
2,640,700	140,000	1,071,000	.....	5,152,000	5,000	681,040	33,000	300,000
2,497,559	4,913,815	191,800	150,000	180,600	970,200	166,000	.....	983,233
182,200	118,150	478,238	1,000	580,600	344,330	74,000	136,500	7,000
250,000	854,900	110,000	325,000	.....	18,010,000	.....	1,200	305,000
14,031,200	388,300	.....	416,000	.....	819,000	25,000	.....	2,404,500
4,936,000	1,190,650	1,980,700	202,500	257,600	561,700	201,000	.....	804,200
4,826,472	949,200	.....	250,100	2,328,750	86,500	.....	.....	336,075
90,900	1,911,897	.....	284,800	.....	282,265	30,000	7,000	1,913,000
77,000	1,354,500	.....	15,000	.....	.....	.....	90,000	8,149,000
956,200	1,562,262	73,000	.....	1,003,800	334,600	10,000	10,000	28,000
1,248,000	1,450,500	.....	1,078,500	.....	22,200	.....	1,400	10,000
2,576,800	854,000	100,000	30,000	.....	85,000	.....	.....	147,500
12,000	2,145,050	.....	1,750,000	.....	.....	.....	.....	240,000
2,637,027	80,000	.....	37,000	.....	1,085,000	.....	.....	52,044
12,000	101,500	10,000	200,000	1,060,000	100,600	30,000	1,000,000	
272,100	703,786	.....	15,000	.....	150,000	30,000	.....	242,200
158,000	451,000	1,820,000	.....	5,000	73,000	500	.....	675,000
20,000	1,101,100	.....	20,000	.....	.....	.....	.....	580,000
405,000	564,500	.....	110,000	.....	.....	.....	.....	530,500
.....	.....	.....	345,000					
.....	147,100	.....	.....	.....	.....	.....	.....	353,000
.....	.....	.....	12,000	.....	.....	.....	.....	2,000
3,500	.....	46,600	.....	.....	4,200			

TABLE XXXI.—QUANTITY OF EACH KIND OF WOOD USED ANNU-

Industry	Kind of wood			
	Hickory, feet b. m.	Basswood, feet b. m.	Cotton-wood, feet b. m.	Chestnut, feet b. m.
All industries	389,604,531	369,640,782	322,642,796	298,849,801
Planing-mill products, sash, doors, blinds, and general millwork	2,489,288	60,557,122	21,428,700	82,267,497
Boxes and crates	767,920	86,979,611	210,519,509	36,216,700
Car construction	1,226,706	5,148,521	3,037,468	825,074
Furniture	843,600	33,146,276	5,158,309	44,734,180
Vehicles and vehicle parts	239,491,910	6,418,308	33,278,658	972,809
Woodenware, novelties, and dairymen's, poulterers', and apiarists' supplies	1,567,011	58,563,923	13,315,296	20,853,100
Agricultural implements	9,860,470	7,861,750	15,143,000	884,000
Chairs and chair stock	1,192,200	1,758,338	126,000	5,240,630
Handles	120,294,466	2,285,885	27,000	10,000
Musical instruments	225	10,968,180	2,351,000	38,125,141
Tanks and silos	.....	5,000	.....	15,000
Ship and boat building	110,195	959,000	14,026	751,295
Fixtures	26,000	7,114,755	1,553,351	8,039,595
Caskets and coffins	.....	2,728,038	555,000	46,586,629
Refrigerators and kitchen cabinets	150,000	5,221,634	4,420,322	1,508,753
Matches and toothpicks	.....	5,575,000	375,000	.....
Laundry appliances	.....	4,980,670	7,991,500	20,500
Shade and map rollers	2,500	702,500	.....	460,000
Paving material and conduits	.....	.....	.....	.....
Trunks and valises	173,700	21,164,406	1,973,325	562,500
Machine construction	1,113,135	1,155,403	293,000	272,375
Boot and shoe findings	25,000	3,599,200	5,000	.....
Picture frames and molding	10,000	20,340,700	1,000	1,314,650
Shuttles, spools, and bobbins	872,000	1,947,000	175,000	.....
Tobacco boxes	.....	4,206,250	6,750	.....
Sewing machines	.....	310,000	326,912	540,000
Pumps and wood pipe	925,000	.....	.....	.....
Pulleys and conveyors	.....	625,000	42,000	120,000
Professional and scientific instruments	971,332	2,619,070	170	367,000
Toys	.....	8,739,242	257,000	966,268
Gates and fencing	600	50,000	.....	5,121,500
Sporting and athletic goods	4,944,000	318,600	60,000	222,000
Patterns and flasks	.....	123,500	.....	175,200
Bungs and faucets	6,000	.....	.....	.....
Plumbers' woodwork	.....	245,000	.....	114,000
Electrical machinery and apparatus	.....	299,000	7,500	112,700
Mine equipment	816,363	.....	.....	854,405
Brushes	125,000	758,300	50,000	31,500
Dowels	30,500	167,500	5,000	.....
Elevators	100	10,000	.....	19,000
Saddles and harness	12,800	52,000	46,000	.....
Playground equipment	100,000	.....	.....	.....
Butchers' blocks and skewers	1,310,000	.....	.....	.....
Clocks	.....	1,415,000	.....	290,000
Signs and supplies	.....	100,000	100,000	.....
Printing material	20,500	352,600	.....	255,800
Weighing apparatus	.....	35,000	.....	.....
Whips, canes, and umbrella sticks	84,000	32,500	.....	.....
Brooms and carpet sweepers	.....	.....	.....	.....
Firearms				
Artificial limbs	40,010	1,000		
Tobacco pipes				
Arplanes	2,000	.....	.....	.....

ALLY IN THE MANUFACTURE OF WOODEN PRODUCTS—*Continued*

Kind of wood								
Ash, feet b. m.	Beech, feet b. m.	Elm, feet b. m.	Tupelo, feet b. m.	Redwood, feet b. m.	Larch, feet b. m.	Cedar, feet b. m.	Sugar pine, feet b. m.	Balsam fir, feet b. m
295,461,482	278,203,632	218,200,988	127,958,309	122,326,779	114,029,275	102,248,253	59,211,298	53,262,030
21,304,374	58,394,284	6,218,860	17,003,448	92,759,519	88,484,081	45,187,611	31,795,077	10,863,300
10,507,308	77,899,280	63,726,458	74,982,910	2,439,500	7,470,300	2,512,150	24,686,000	40,173,700
18,163,433	1,873,700	1,221,121	114,168	120,000	1,537,669	339,487	61,328	700,750
15,668,588	21,163,204	12,154,102	2,529,000	355,250	154,000	1,856,100	375,510	
43,974,668	5,497,743	31,296,922	1,067,600	259,000	.....	2,500	6,000	1,000
62,635,800	14,101,553	16,383,426	5,366,900	3,208,150	416,700	6,405,470	419,063	586,880
10,677,400	4,968,490	7,249,000	1,140,000	200,500	100,000	.....	50,000	
2,765,050	27,187,621	23,157,586	191,000	.....	.....	34,500		
64,156,872	16,691,207	3,060,307						
2,377,332	4,186,000	15,602,440	460,000	286,200	.....	17,500	1,004,400	101,400
866,000	150,000	15,000	20,000	8,124,938	9,745,000	4,549,400	10,750	
7,985,551	219,366	706,600	138,490	837,500	328,525	6,999,722	200,500	
2,783,822	1,109,000	6,368,275	248,000	1,074,710	2,000	977,345	206,650	
20,000	.....	.....	500,000	1,782,000	.....	5,901,718		
19,066,380	787,000	13,046,100	39,500	161,000	56,000	.....	.....	710,000
.....	.....	.....	.....	.....	.....	407,500		
111,500	9,580,000	1,365,000	3,842,000	13,000	.....	4,867,000	2,000	100,000
161,150	362,000	.....	1,006,000	2,000	.....	5,000	30,000	
.....	.....	.....	1,050,000	.....	4,475,000	100,000		
534,435	520,000	6,409,286	.....	.....	.....	6,000	11,000	25,000
1,404,362	711,000	831,000	27,500	58,500	.....	100	4,000	
.....	445,000	2,000						
281,845	1,200,595	43,000	240,000	47,632	.....	.....	2,730	
437,000	3,523,500	.....	250,000					
.....	.....	1,809,000	10,376,217	61,000	.....	246,750		
.....	.....	.....	2,200,000	16,000				
975,500	52,500	20,000	529,500	9,117,500	512,000			
512,100	1,976,000	200,000	639,000					
123,600	1,259,600	200	12,000	31,220	.....	20,050,000	23,500	
895,300	3,221,506	2,042,055	5,000					
700	.....	155,000	.....	133,000	48,000	465,500		
3,180,000	212,000	3,226,750	20,000	.....	.....	222,500		
35,000	10,500	40,000	500	1,033,200	.....	265,400	294,350	
.....	850,000	.....	.....	2,000	.....	30,000		
536,000	.....	55,000						
87,000	425,000	463,000	.....	.....	700,000	735,000		
43,425	1,195,525	8,800	3,589,760					
36,400	6,378,894	187,000	1,000	.....	.....	24,000	3,440	
29,000	1,834,000	175,000	.....	.....	.....	18,000		
145,700	.....	68,500	15,000	36,000	.....	.....	15,000	
2,103,000	2,658,600	276,000	20,000	.....	.....	.....	10,000	
180,000	3,083,500	334,000	1,00					
20,000	920,000							
.....	9,714	.....	322,816					
.....	.....	200,000	.....	147,460	.....	20,000		
391,000	289,900	84,200	10,000	20,000				
5,900	335,000							
30,000	2,822,500	.....	.....	.....	.....	2,000		
236,984	98,350							
12,000								

TABLE XXXI.—QUANTITY OF EACH KIND OF WOOD USED ANNU-

Industry	Kind of wood			
	Mahogany, feet b. m.	Spanish cedar, feet b. m.	Sycamore, feet b. m.	Black walnut, feet b. m.
All industries	50,575,999	30,323,441	26,052,812	23,988,346
Planing-mill products, sash, doors, blinds, and general millwork	7,336,932	8,123	1,723,550	4,606,420
Boxes and crates	13,000	.....	16,451,693	163,250
Car construction	5,986,198	.....	.....	256,181
Furniture	15,637,125	2,500	1,474,882	1,689,957
Vehicles and vehicle parts	516,399	500	62,600	390,450
Woodenware, novelties, and dairymen's, poulterers', and apiarists' supplies	72,305	10,000	607,500	38,547
Agricultural implements	500	.....	290,000	8,000
Chairs and chair stock	2,455,700	.....	971,344	263,200
Handles	29,000	.....	156,000	29,050
Musical instruments	8,610,355	7,750	304,600	4,991,808
Tanks and silos	.....	.....	.....	.....
Ship and boat building	1,190,192	27,300	38,000	3,750
Fixtures	5,527,819	.....	713,000	660,635
Caskets and coffins	1,528,294	300	.....	474,000
Refrigerators and kitchen cabinets	6,800	.....	340,000	.....
Matches and toothpicks	.....	.....	.....	.....
Laundry appliances	.....	.....	2,000	20,000
Shade and map rollers	5,000	.....	202,000	2,000
Paving material and conduits	.....	.....	.....	.....
Trunks and valises	500	.....	5,000	.....
Machine construction	5,885	.....	.....	10,817
Boot and shoe findings	.....	.....	.....	.....
Picture frames and molding	171,200	.....	30,000	125,004
Shuttles, spools, and bobbins	.....	.....	.....	.....
Tobacco boxes	161,200	30,203,068	430,000	.....
Sewing machines	91,878	.....	150,000	7,796,815
Pumps and wood pipe	.....	.....	.....	.....
Pulleys and conveyors	.....	.....	.....	.....
Professional and scientific instruments	84,862	.....	.....	71,200
Toys	.....	.....	91,343	.....
Gates and fencing	.....	.....	.....	.....
Sporting and athletic goods	100,000	31,500	30,500	41,000
Patterns and flasks	271,659	31,400	.....	21,500
Bungs and faucets	.....	.....	.....	56,000
Plumbers' woodwork	127,000	.....	.....	10,300
Electrical machinery and apparatus	301,700	.....	.....	452,600
Mine equipment	.....	.....	.....	.....
Brushes	35,300	1,000	74,300	26,700
Dowels	.....	.....	.....	.....
Elevators	1,000	.....	.....	.....
Saddles and harness	.....	.....	34,500	.....
Playground equipment	.....	.....	.....	.....
Butchers' blocks and skewers	.....	.....	1,600,000	.....
Clocks	204,196	.....	.....	58,527
Signs and supplies	.....	.....	.....	.....
Printing material	48,500	.....	.....	.....
Weighing apparatus	4,000	.....	.....	.....
Whips, canes, and umbrella sticks	15,000	.....	.....	20,000
Brooms and carpet sweepers	30,500	.....	270,000	500
Firearms	.....	.....	.....	1,700,135
Artificial limbs	.....	.....	.....	.....
Tobacco pipes	.....	.....	.....	.....
Airplanes	6,000	.....	.....	.....

ALLY IN THE MANUFACTURE OF WOODEN PRODUCTS—*Continued*

Kind of wood								
Cherry, feet b. m.	White fir, feet b. m.	Willow, feet b. m.	Dogwood, feet b. m.	Noble fir, feet b. m.	Magnolia, feet b. m.	Buckeye, feet b. m.	Miscellaneous native, feet b. m.	Miscellaneous foreign, feet b. m.
12,047,210	11,338,580	10,664,770	7,518,177	6,653,500	6,156,500	5,486,047	20,085,612	8,301,422
1,671,235	8,162,250	266,000	6,000	.....	116,900	694,400	5,191,050	1,507,047
170,500	3,142,080	10,004,600	.....	6,653,500	5,449,000	3,174,028	3,363,938	
1,965,570	.....	.....	.....	.....	.....	.....	1,031,300	896,001
622,530	.....	40,000	.....	.....	477,100	415,000	1,575,850	1,434,373
39,650	3,000	.....	.....	.....	9,500	63,419	848,626	19,250
62,350	31,250	128,000	34	.....	.....	83,700	1,246,650	25,015
300	.....	.....	.....	.....	.....	.....	32,300	
56,000	.....	.....	.....	.....	.....	.....	645,546	11,300
617,500	.....	19,000	190,230	.....	.....	.....	946,600	270,386
334,180	.....	.....	.....	.....	.....	6,000	102,680	458,811
500								
184,976	.....	1,000	.....	.....	.....	.....	616,415	862,365
2,231,750	.....	150,000	.....	.....	27,000	10,000	411,200	388,780
33,000	.....	.....	.....	.....	.....	207,500	37,718	10,000
7,500	.....	.....	.....	.....	.....	.....	.....	500
2,000	.....	.....	.....	.....	.....	125,000		
2,000	.....	.....	.....	.....	.....	.....	5,000	3,300
.....	.....	.....	.....	.....	.....	415,000		
69,500	.....	.....	.....	.....	.....	.....	11,600	961
25,000	.....	.....	.....	.....	.....	.....	413,000	
10,000	.....	.....	.....	.....	.....	214,000	20,000	13,000
5,000	.....	.....	7,060,425	.....	.....	.....	2,909,760	105,055
.....	.....	.....	.....	.....	75,000	.....	.....	36,950
.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	300	
.....	.....	.....	.....	.....	.....	.....	25,500	72,300
732,750	.....	.....	31,200	.....	.....	.....	55,000	976,737
2,000	.....	.....	.....	.....	.....	.....	10,000	
600	.....	.....	6,000	.....	.....	.....	207,500	482,450
165,594	.....	.....	.....	.....	.....	3,000	43,210	3,200
.....	.....	.....	.....	.....	.....	.....	14,600	10,642
92,400	.....	.....	.....	.....	.....	.....	.....	1,000
27,800	.....	.....	.....	.....	.....	.....	2,000	15,680
.....	.....	.....	147,288	.....	.....	.....	53,034	
488,900	.....	.....	9,000	.....	2,000	.....	22,000	29,390
10,000	.....	.....	1,000					
.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	54,000	
15,000	.....	.....	67,000	.....	.....	.....	.....	.....
300,000	.....	.....	.....	.....	.....	.....	.....	290
.....	.....	.....	.....	.....	.....	75,000		
2,089,625	.....	.....	.....	.....	.....	.....	1,000	33
7,500	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	219,780
.....	.....	.....	.....	.....	.....	.....	5,000	26,000
.....	.....	.....	.....	.....	.....	.....	.....	48,766
10,000	.....	56,170	.....	.....	.....	.....	39,800	40,000
.....	.....	.....	.....	.....	.....	.....	143,435	332,080

ratus, brattices, breaker equipment, slope rollers, and sprags. Dowels are small rods used in fastening together furniture, fixtures, and doors. Under playground equipment come lawn swings and porch furniture.

The kinds of wood are classified according to rather broad commercial practice. The classification is practically the same as that used in the lumber census bulletins; figures on the several species of each family or group are combined under the common name.

Oak, maple, spruce, hemlock, birch, hickory, basswood, ash, elm, cedar, willow, locust, and eucalyptus each covers its different species.

Yellow pine includes the southern yellow pines, North Carolina pines, and minor eastern yellow pines. Western yellow pine is listed separately; trade names for it are western pine, western soft pine, and California white pine.

White pine covers both northern and western (Idaho) white pine as well as Norway pine and jack pine.

Cottonwood takes in the cottonwoods, aspen (or popple), and balm of Gilead.

Tupelo includes cotton gum (called tupelo commercially), black gum, and water gum.

Larch includes western larch and eastern tamarack.

Mahogany covers all woods sold in this country as such.

White fir includes the botanical white fir as well as grand and silver (amabilis) fir; the other minor firs, noble, red, and alpine fir, usually sold as white fir, are listed separately.

(*b*) *Slack Cooperage.*—By slack cooperage is meant barrels, kegs, candy and tobacco pails, lard and butter tubs, and, in fact, all containers made of staves and used for purposes other than holding liquids. Cooperage stock consists of staves, heading, and hoops. It is usually manufactured in the rough at the mill, and remanufactured into the finished product at a cooperage shop. Barrel staves and hoops are sliced by means of a heavy knife from bolts which have previously been softened by immersion in hot water. Staves for tubs and pails and some barrel staves, hoops, and all heading are cut with a saw.

The slack cooperage industry reached its maximum in 1909 when over 2 billion staves were produced. The substitution of veneer for staves in barrels; and the substitution of other containers, as boxes for apples; cotton, jute, and paper sacks for flour and cement barrels were important factors in cutting down the production of slack staves to a present use of 1 billion. In 1890, 44.7 per cent of all flour shipped out of Minneapolis was contained in barrels, whereas in 1914 only 6.8 per cent was shipped in barrels.

The requirements for slack cooperage stock are not very stringent. Woods which steam easily, dry quickly, and retain their form when bent, and which do not contain resin or other substances likely to taint or discolor the contents, make the best slack barrel material. However, the choice of species is governed more by cheapness and availability of the timber than by special qualities of the wood. Elm, because it cuts easily and bends readily without breaking, is preferred for flour barrels. Ash is the principal wood used for lard and butter tubs. The principal woods used for slack staves are red gum and pine, while beech, elm, chestnut, spruce, ash, maple, birch, oak, Douglas fir, and cottonwood are used in smaller quantities. For headings, the same woods are used but do not rank the same in amounts used. Woods light in color, easily worked, and free from warping are preferable for heading. Basswood is highly prized for flour-barrel heading.

For hoops, elm is used almost exclusively because it is easily manufactured, easily bent, and cheaper than ash, oak, or hickory, which would also be excellent for the purpose.

(*c*) *Tight Cooperage and Tanks.*—By tight cooperage is meant all forms of barrels, half barrels, kegs, and similar containers made of staves and meant to hold liquids. Only a limited number of woods are useful for this purpose. Strength and a high degree of imperviousness are the chief requirements of wood for tight cooperage, although freedom from taste and resistance to decay also are essential. The woods of the white oak group possess these properties to a remarkable degree. About one-half of all staves cut are of this group. Red oak allows liquids to pass through more easily and is less in demand for this purpose. Other woods used for tight cooperage are gum, birch, maple, ash, Douglas fir, spruce, white pine, and basswood. Arkansas produces more oak staves than any other state in the union. This is due to the large amounts of suitable white oak in that state. The total number of tight cooperage staves used annually is about 286,000,000. Tight cooperage staves are practically always cut radially because when so cut the shrinkage in width is less and the seepage of liquids through the staves is less than when cut tangentially. Figure 122 shows a cylindrical saw such as is used for cutting staves from split bolts.

Wooden tanks are principally of two kinds, vertical stave and square end. The woods used must be fairly impervious to

liquids; and if used for water, should be highly resistant to decay. The heartwood only should be used. Cedar, cypress, and redwood are especially recommended for this purpose. If cedar is used, the staves must be allowed to leach for some time if the water is to be used for drinking purposes, because the fresh cedar imparts a taste to liquids in contact with it. Redwood staves will impart a red color to the water for some time, but eventually this will cease. Dense resinous yellow pine and Douglas fir, the larches, and white pine make satisfactory tanks but do not possess the great durability of cedar, cypress, and redwood. White oak gives satisfactory service but is expensive and difficult to work.

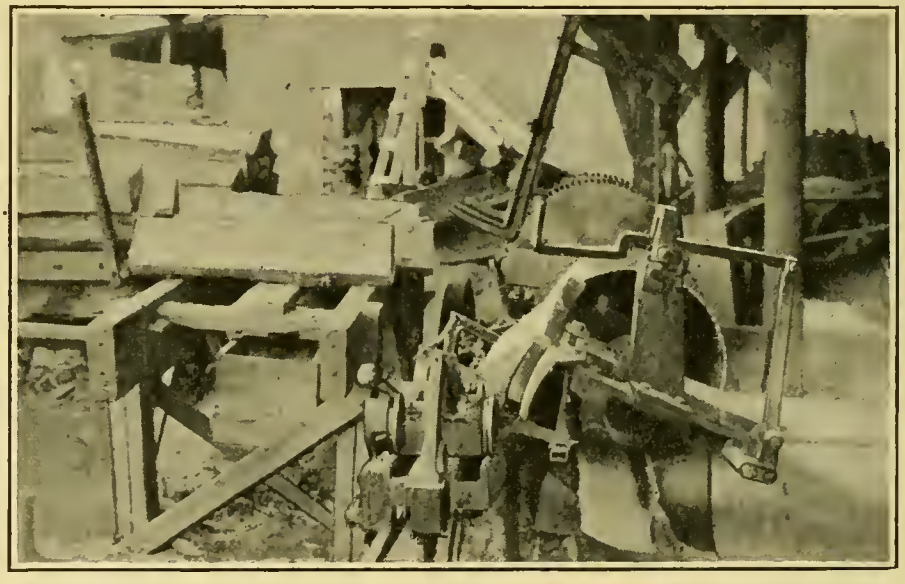

FIG. 122.—Stave mill showing cylindrical saw for cutting staves from split bolts. (*Photograph by the author.*)

(*d*) *Wooden Stave Pipe.*

Two distinct types of wooden pipe are in general use, continuous stave and machine banded. The former is assembled in place, and consists of wooden staves banded with steel hoops, which are tightened by shoes and nuts. The pipe, as a whole, has no joints in the sense that it is not built in lengths. Machine banded pipe is built up in lengths at the factory, usually in diameters not greater than 24 inches. It is made from staves and from solid logs properly bored. Continuous stave pipe is usually not made in sizes smaller than 20 inches, though it has been made as small as 10 inches. Lines as large as 14 feet in diameter have been installed, and 6 and 8 foot lines are not at all unusual. One of the principal advantages of continuous stave pipe, especially in the West, lies in its low cost and the ease with which the material for its construc-

tion can be procured, transported, and assembled in regions remote from railroads and difficult of access.[1]

In fact wooden stave pipe is used most commonly in the western country where timber is abundant. It is used especially for conveying municipal water supplies, and also for power development and irrigation purposes. Figure 123 shows the method of constructing a continuous wooden stave pipe.

The advantages of stave pipe are given in United States Department of Agriculture *Bull.* **155**[2] as follows:

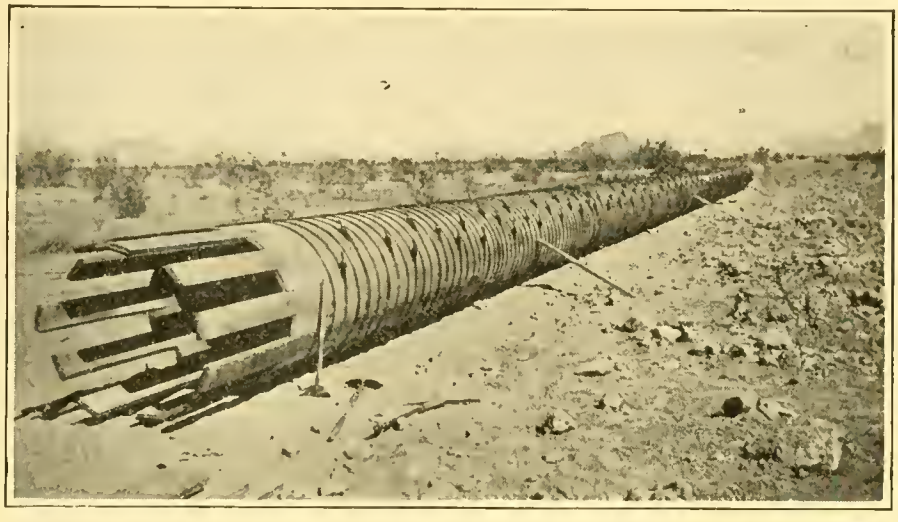

FIG. 123.—Continuous wooden stave pipe in process of construction.

In addition to its low first cost, experience has shown that wood pipe has other advantages as compared to cast iron or steel pipe. It is not so subject to injury from freezing, settling, or expansion and contraction due to extremes of temperatures, while if injury is sustained, extra materials can usually be obtained readily, and repairs can be made much more quickly and with less expense than would be required for pipes of iron or steel. Furthermore, the capacity of wood pipe is probably somewhat greater than that of iron or steel of equal size, and may, under favorable conditions, increase with time instead of being reduced by tubercles and corrosion such as occur in the other kind of pipe mentioned.

Deterioration usually takes place by wearing away of the wood, rusting of bands, or decay of the wood. The last named is the most serious. It has been found that if the pressure in the pipes is great enough to keep the wood saturated it will last a very long

[1] THELEN, ROLF, "The Substitution of other Materials for Wood." *Rept.* **117** of the Office of the Secretary of the Department of Agriculture.

[2] JAYNE, S. O., "Wood Pipe for Conveying Water for Irrigation."

time because of the exclusion of the air which is necessary for fungous growth. According to O. P. M. Gross[1] when the pipe line is under less than 20 foot head hydrostatic pressure it is subject to decay. Stave pipe is more easily kept saturated when covered with ground, especially compact clayey soil. If the internal pressure is low, or if the pipe is not full, wooden pipe will decay more rapidly under ground than if kept above ground where the outer surface of the staves remain dry. If the wooden staves are given a preservative treatment with creosote, their length of life should be increased from two to six times that of the untreated pipe.

Redwood is the principal wood used for pipe made in San Francisco, and Douglas fir is used at other western points. In the East, white pine, tamarack, and cypress are the principal woods used.

(*e*) *Boxes and Crates.*[2]—Special mention is made here of wood used for packing boxes and crates because of the enormous amount of lumber used by the box industry and the peculiar relation in which this industry stands toward the lumber industry. Exclusive of the great demands of wood for general construction and planing-mill products, more lumber is used in making boxes and crates than in any other industry. Low grades, such as No. 2 and No. 3 common, or a special grade known as "box" can be used for this purpose with satisfactory results because of the temporary use of packing boxes; because appearances usually are of secondary importance; and because the lumber is used in short lengths making it possible to cut out serious defects.

Lumber manufacturers are usually able to dispose of their higher grades of lumber, but the lower grades serve a very limited demand. Fortunately, the box industry is able to use a large amount of this poor material and so makes possible the closer utilization of the forest.

Box makers cannot be very particular in the selection of species, although even for packing boxes there are certain requirements which make some wood more desirable than others. The wood

[1] "Structural Timber Handbook on Pacific Coast Woods," published by the West Coast Lumbermen's Association.

[2] For detailed information on the use of wood for boxes see "Wooden Box and Crate Construction" prepared by the Forest Products Laboratory and published by the National Association of Box Manufactures, Chicago, 1921.

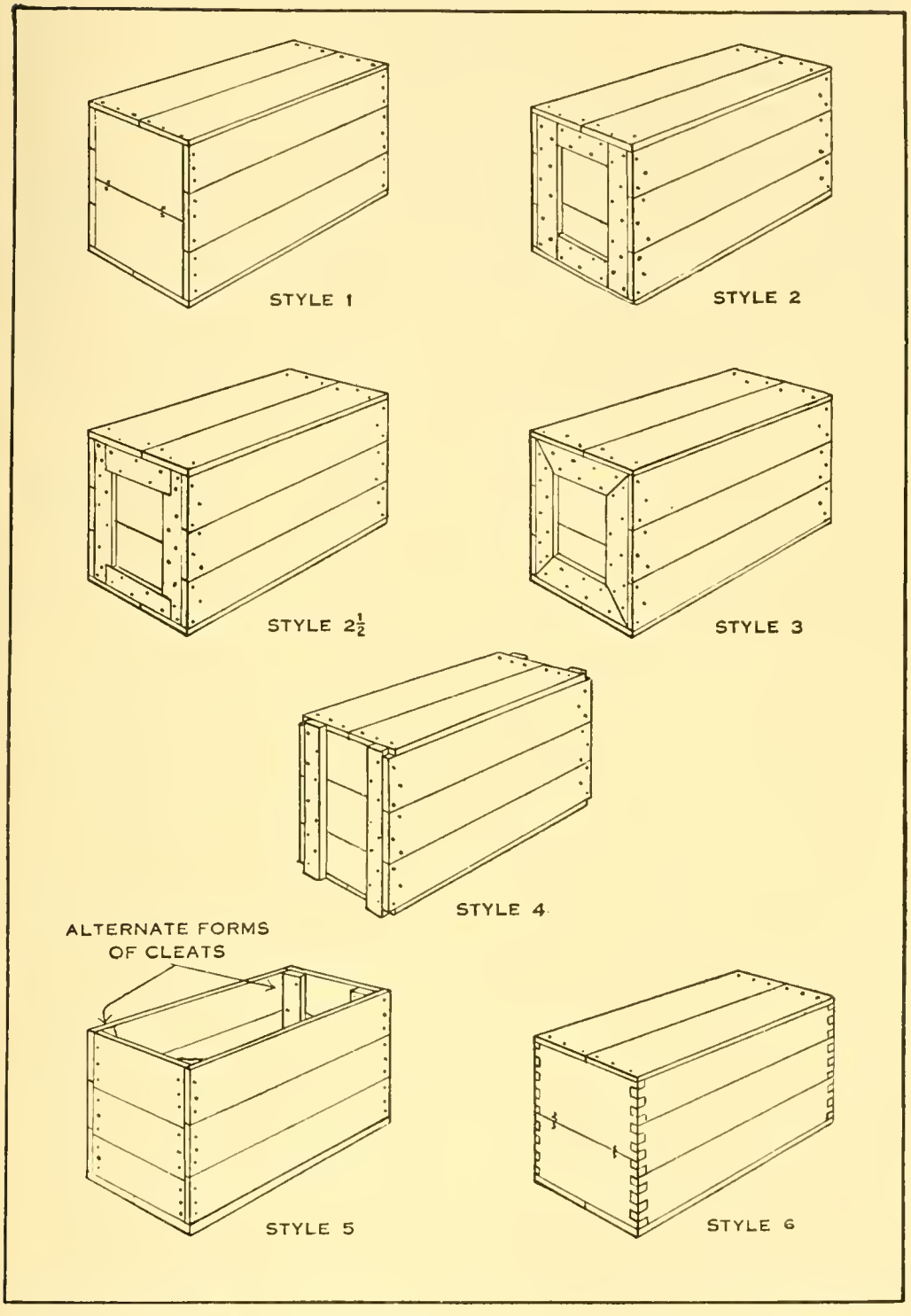

FIG. 124.—Styles of wooden boxes, nailed and lock-corner construction. (*Courtesy, Forest Products Laboratory.*)

should be cheap, abundant, fairly light, easily worked, comparatively free from warping, light in color so that addresses and advertising will be readily visible, and should not split easily in nailing. For containers of certain foods the lumber must be free from objectionable odors.

In view of the fact that the supply of white pine is said to be almost exhausted, it is interesting to note that it is used extensively for making packing boxes. The white pine lumber used for boxes, however, is cut from tops, low grade logs, and second growth timber, and, therefore, contains numerous knots and other defects. Another reason for the extensive use of white pine is that it combines to a remarkable degree the qualities previously enumerated as desirable for boxes.

Yellow pine produces an almost equal amount of box lumber and together with white pine constitutes about one-half of the total of 4½ billion board feet of lumber used annually in the manufacture of packing boxes. Many other species, in fact all except the extremely hard and rare woods, are used to some extent by the box industry, as can be seen from Table XXXI. Figure 124 shows styles of wooden boxes and methods of nailing recommended by the Forest Products Laboratory, U. S. Forest Service.

114. Utilization of Logging, Mill, and Factory Waste.—Upon the efficient utilization of their by-products and waste materials depends the success of many industries. In the lumbering and wood-working industries there is an enormous amount of waste some of which could undoubtedly be converted into useful products. According to the report of the National Conservation Commission,[1] on the average out of every 1,000 board feet of standing timber only 320 feet are actually put to use, or, by taking stumps, tops, limbs, and small and defective trees into consideration, only about one-fourth of the wood in the forest is actually used, as is indicated in Fig. 118.[2] The waste occurs in

[1] *Senate Document* **676**, "Report of the National Conservation Commission."

[2] In an address before the meeting of the Northern Hemlock and Hardware Manufacturers' Association held at Milwaukee, April 23, 1913, R. B. Goodman of the Goodman Lumber Company of Goodman, Wis. stated that in a hardwood operation they were able to take to the mill with profit only 30 to 35 per cent of the weight of the wood on the land, leaving 65 to 70 per cent of the forest on the ground as having no economic value. At the mill only 50 per cent of the log was converted into lumber, 30 per cent into fuel, and 20 per cent of the log was waste or available for whatever

logging, in sawing at the mill, in seasoning, and in the manufacture of the lumber into the final products.

Over 50 per cent of the volume of the timber brought to the mill is wasted at the mill. For the entire lumber cut of the United States under present practices the waste in milling has been estimated as 13 per cent of the volume of the log for bark, another 13 per cent for saw kerf, 12 per cent for edgings and trimmings, 12 per cent for slabs, and 3 per cent for careless manufacture and accidents. The average waste in seasoning is estimated as 6.7 per cent. In cutting lumber to the desired sizes in building construction and wood-working plants from 11 to 25 per cent of the sawed lumber becomes waste.

After deducting all this waste there is left on the average only about 25 per cent of the wood as found in the forest which actually appears in the finished articles. Of course, much of this waste cannot be avoided under present conditions of labor and market. It has been shown in actual practice, however, that it is possible to reduce the amount of waste by more careful methods of logging; by taking to the mill more of the defective and inferior kinds of trees; by using, whenever possible, band saws instead of circular saws which cut a wider kerf; by not cutting lumber to standard sizes; by using round-edge or "wany" lumber as is now done to some extent in the New England States, by the adoption of proper seasoning methods; by greater care in manufacture; by greater care in the use of lumber; by working up the offal into small articles; and by converting chemically what would otherwise be waste.

The following uses of wood waste are given here in the belief that their enumeration will suggest some possible use of the waste which is left by the logger or which accumulates at the mill and factory, and often requires time and money for its removal. The great difficulty is in getting the stuff to the place where it might be used. Handling this small material several times and shipping it some distance to a factory or chemical plant usually makes it too expensive, thereby prohibiting its use.

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use could be made of it. According to these figures only 15 to 17½ per cent of the weight of standing timber in a hardwood forest can be profitably cut into lumber under the most improved conditions of manufacture. *Hardwood Record*, April 25, 1913.

(*a*) *Utilizing What the Logger Leaves.*—Experience has shown that it is often profitable to follow a logging operation, especially after a number of years during which time conditions have changed, and remove some of the remaining timber. This material is in the form of small trees,[1] defective trees, inferior species, dead and down timber, long tops, large limbs, and stumps. The use that can be made of this material depends upon the local market. It may be profitable to dispose of a certain amount of this material for some of the following purposes:

Lumber: Portable sawmills cut up all species that are not too small or too defective.

Dimension Stock: Small pieces, such as are used for chairs, implements, and turned products in general can often be cut to advantage out of logging waste.

Lath: Certain species can be converted into lath more profitably than into other material.

Shingles: Short pieces of defective logs of certain species make acceptable shingle bolts.

Fence posts: Small trees and tops may be salable as posts, especially if of a kind that is fairly durable in the ground.

Poles and piling: Trees less than 12 inches in diameter are often undesirable for saw logs but can be used for poles and piling if the taper is not too great.

Ties: Short, small timber may bring a good price if cut into railway ties. Many kinds, however, are not taken by railway companies.

Mining timber: Pieces over 3 inches in diameter of practically all species are salable in mining regions for props, etc.

Pulpwood: If the proper species are available, a better price can often be obtained when sold to pulp mills than can be obtained from any other source. Crooked timber is as suitable as straight logs for pulp.

Excelsior: Aspen, which very commonly grows on logged-over areas, may be disposed of to excelsior mills, also basswood, balsam, and other species.

Distillation wood: Birch, beech, maple, oak, and ironwood are the principal species desired at wood distillation plants. Small logs, crooked pieces and even limbs are suitable for this purpose.

Extract wood: Chestnut can readily be sold in certain regions to extract plants.

Kilnwood: If the wood left after logging is not suitable for the above purposes, a day's wages can often be made and the land cleared by cutting

[1] If another crop of timber is expected from the land, small trees of valuable species should not be cut, some trees should be left for seed, and as little damage as possible done to the young growth. On the other hand removing the dead and down timber reduces the fire hazard.

up defective timber into cordwood lengths and disposing of it at lime and brick kilns.

Stovewood: In newly developed regions, wood is commonly used for fuel, thus affording a market for many species.

(*b*) *Utilizing Sawmill and Factory Waste.*—Wood waste at the sawmill, planing mill, and factory falls into several classes as slabs, edgings, trimmings, bark, sawdust, and shavings.

Slabs, edgings, and trimmings have been manufactured into the following articles at a profit.

Lath
Boxes and crates
Woodenware and novelties
Furniture
Chairs and chair stock
Shades and map rollers
Matches and toothpicks
Boot and shoe findings
Toys
Brushes
Tenpins
Dowels and clothespins
Broom handles and carpet sweepers
Skewers and butcher blocks

The chemical conversion of waste into useful products has been discussed in Chap. VI. It includes hardwood distillation, softwood distillation, extraction of resin, manufacture of pulp and paper, and other processes.

The most important use of waste as far as quantity is concerned, is for fuel, but this of course brings a minimum price not comparable with the value of wood as lumber if it can be used in any other way. Even if the waste wood is burned in a refuse burner, it may under certain conditions be profitable to leach the ashes for the potash they contain.

Bark accumulates in great quantities at pulp mills, sawmills, and tanneries after the tannin is extracted. It is usually looked upon as a necessary evil. Lately several uses have been made of such material, for example, filler in paper, cardboard, wallboard, roofing felt, composition shingles, and for ornamental purposes in "oatmeal" wall papers.

Sawdust and shavings form a large amount of waste at mills and wood-working plants. They are used mostly for fuel under boilers at the plants where they are produced. Other uses are:

Bedding in stables
Insulating in ice houses, cars, etc.
Sound deadening of floors and walls
Packing of all kinds
Composition flooring
Floor-sweeping compounds
Stuffing of cushions and dolls
Fur dressing
Cleaning and drying of metals
Meat smoking
Absorbents on floors, walks, etc.
Manufacture of gritty soaps
Mixing with cements, mortars, and plasters
Burning porous clay products
Filtering medium
Circus rings
Moth preventive.

CHAPTER XIII

MEASUREMENT OF TIMBER PRODUCTS

The units by which wood is measured vary with the class of material and the part of the country in which it is sold. The quantity may be measured in board feet, cubic feet, cords, by the piece or number of pieces, linear foot, or surface measure. Logs usually are scaled in board measure, but occasionally they are bought by the cord, especially when in small sizes. Ties are usually sold by the piece, but some mills prefer to sell them according to the number of board feet they contain.

To one not familiar with the various forms of measurement, considerable confusion may result from the use of different units for the same class of material, a subterfuge made use of by unscrupulous dealers, who prefer the unit which is to their advantage.

115. Units of Measurement. (*a*) *Board Feet.*—Theoretically, the board foot is a piece of lumber 1 foot square and 1 inch in thickness. It was originally applied to sawed lumber but soon became the common measure for the contents of saw logs. It is also used to some extent for poles, mine timbers, flitches, ties, and shingle or other bolt material over 12 inches in diameter. The board foot measure does not designate the actual volume of wood in a log but rather the amount of sawed lumber it is expected to yield. Since the yield depends upon the size of the logs, whether sawed with a circular saw or band saw, on the character of the defects, and on the care taken in sawing, it is not surprising that many different log rules have been devised. Some rules are based on mathematical formulae, some on diagrams of logs, and some on actual mill tally, each being originally designed for certain conditions. The number of board feet determined for a log of a given size varies considerably with the different log rules as can be seen from Table XXXII.

Logs are always scaled according to the diameter of the top end inside the bark; therefore, a tree trunk cut up into several short logs measures more in board feet than the same size of trunk cut into one or two logs.

TABLE XXXII.—COMPARISON OF LOG RULES

(The values given are for 16-foot logs only[a])

Top diameter of log inside bark.	Scribner.		Doyle	Doyle and Scribner	Holland or Maine	Blodgett or New Hampshire	Humphrey or Vermont	Bangor	Cumberland River	Square of three-fourths	Herring	Champlain	Tiemann
	Scribner	Decimal C											
In.	Contents—(board feet)												
4	(10)	(10)	.....	.....	(3)	13	11	(6)	8	12	(6)	8	9
5	(13)	(10)	1	1	(11)	19	16	(12)	12	19	(12)	14	15
6	18	20	4	4	20	26	24	23	17	27	(19)	22	23
7	24	30	9	9	31	35	32	27	23	37	(26)	32	32
8	32	30	16	16	44	43	43	41	31	48	34	43	43
9	42	40	25	25	52	54	53	54	39	61	43	56	55
10	54	60	36	36	68	66	67	69	47	75	53	70	69
11	64	70	49	49	83	78	80	84	57	91	65	87	84
12	79	80	64	64	105	92	96	100	68	108	77	105	101
13	97	100	81	81	120	106	112	118	80	127	91	124	119
14	114	110	100	100	142	123	131	137	93	147	107	146	139
15	142	140	121	121	161	139	149	158	107	169	124	168	160
16	159	160	144	144	179	157	171	182	121	192	142	193	183
17	185	180	169	169	205	176	192	209	137	217	162	219	207
18	213	210	196	196	232	197	216	238	153	243	183	247	233
19	240	240	225	225	271	217	240	268	171	271	206	277	260
20	280	280	256	256	302	240	267	300	190	300	230	308	289
21	304	300	289	289	336	262	293	334	209	331	256	341	319
22	334	380	324	324	363	287	323	369	229	365	284	376	351
23	377	380	361	361	401	313	352	406	250	397	313	412	384
24	404	400	400	400	439	339	384	444	273	432	344	450	419
25	459	460	441	441	477	367	416	484	296	469	377	490	455
26	500	500	484	484	507	397	451	526	320	507	411	532	493
27	548	550	529	529	546	426	485	566	345	547	447	575	532
28	582	580	576	582	614	457	523	609	372	588	485	620	573
29	609	610	625	609	657	489	560	652	399	631	525	666	615
30	657	660	676	657	706	514	600	697	427	675	567	714	659
31	710	710	729	710	755	557	640	743	456	721	616	764	704
32	736	740	784	736	795	592	683	792	485	708	655	814	751
33	784	780	841	784	848	628	725	842	516	817	703	868	799
34	800	800	900	800	900	666	771	892	548	867	752	923	849
35	876	880	961	876	949	704	816	(950)	581	919	(800)	980	900
36	923	920	1,024	923	1,026	744	864	(1,000)	614	972	(850)	1,038	953
37	1,029	1,030	1,089	1,029	1,089	785	912	(1,050)	649	1,027	(910)	1,097	1,007
38	1,068	1,070	1,156	1,068	1,135	827	963	(1,110)	685	1,083	(960)	1,159	1,063
39	1,120	1,120	1,225	1,120	1,209	870	1,013	(1,170)	721	1,141	(1,020)	1,222	1,120
40	1,204	1,200	1,296	1,204	1,261	914	1,067	(1,220)	759	1,200	(1,080)	1,287	1,179

[a] The Tiemann rule is a good standard for purposes of comparison. It is not in common use, but gives the actual amount of lumber that can be slash sawed from average sound logs by a circular saw cutting a $\frac{3}{16}$-inch kerf. This table shows that the Scribner rule underestimates the amount of lumber that can be sawed from small logs, but for those 20 inches and up it comes very close to the truth. The Doyle rule underestimates still further the contents of small logs, but overestimates those of large logs.

In some states one log rule has been made the legal rule and must be observed when no log rule is specified in contracts for selling logs. If buyer and seller agree, however, to use a different rule, no objection is made. In other states it is illegal to use any rule other than the statute rule.

In measuring lumber a so-called board foot does not always contain fully 144 cubic inches, that is, the actual dimensions may be somewhat less than the nominal dimensions, especially after the material is dressed. Dimension stock is often scant in measurement. This is due to the difficulty of sawing timbers true, to the decrease in dimension as a result of seasoning and surfacing, and to the practice of lumbermen of making dimensions purposely scant to save timber and reduce freight rates.

Furthermore, the actual dimension for a specified size is not standardized all over the country. A "2 by 8" hemlock joist surfaced one side and one edge (S1S1E) measures $1\frac{3}{4}$ by $7\frac{3}{4}$ inches, while a "2 by 8" yellow pine joist S1S1E measures $1\frac{5}{8}$ by $7\frac{1}{2}$ inches.

This practice of selling lumber scant in measurement is recognized by the courts but causes considerable inconvenience in many ways.

The dimensions of a piece of lumber are written in the following order: first the thickness, then the width, then the length. Thus 16 pcs. $2 \times 4 - 16$ means 16 pieces of lumber each of which is 2 inches thick, 4 inches wide, and 16 feet long.

To find the number of board feet when the number and size of the pieces are given, use the following formula:

$$\frac{\text{number of pieces} \times \text{thickness in inches} \times \text{width in inches} \times \text{length in feet}}{12} =$$

board feet. Accordingly, the above 16 pieces would contain

$$\frac{16 \times 2 \times 4 \times 16}{12} = 170\,\tfrac{2}{3} \text{ board feet.}$$

Converting figures used by the United States Forest Service for reducing various timber products to feet board measure are given in Table XXXIII. The following equivalents are also in use:

1,000 slack cooperage staves 30 inches long and 4 inches wide are equivalent to 416.6 board feet log scale (Doyle rule).

1,000 sets of slack cooperage heading $\frac{7}{16}$ inch thick and $19\frac{1}{2}$ inches in diameter when dry are equivalent to 714.3 board feet log scale (Doyle rule).

1,000 tight cooperage staves 34 inches or 36 inches long and $4\frac{1}{2}$ inches wide are the equivalent of 1,700 board feet log scale (Decimal C rule).

1,000 sets of tight cooperage heading are equivalent to from 2,857 to 3,333 board feet (Decimal C rule).

1,000 shingles 16 inches long, 6 butts 2 inches thick, contain 86.20 board feet.
1,000 shingles 16 inches long, 5 butts 2 inches thick, contain 100.28 board feet.
1,000 shingles 18 inches long, 5 butts 2 inches thick, contain 115.78 board feet.
1,000 shingles 18 inches long, 5 butts 2¼ inches thick, contain 127.65 board feet.
1,000 shingles 24 inches long, 5 butts 2½ inches thick, contain 236.91 board feet.

TABLE XXXIII.—CONVERTING EQUIVALENTS

Product	Assumed dimensions	Equivalent in board feet
Long cord (acid wood, pulpwood, and distillation wood)	4′ × 5′ × 8′	625
Cord (spruce pulpwood)	4′ × 4′ × 8′	560
Cord (shingle bolts)	4′ × 4′ × 8′	600
Cord (fuel material averaging 5 inches or less in middle diameter)	4′ × 4′ × 8′	333⅓
Cord (fuel material averaging 6 inches or more in middle diameter)	4′ × 4′ × 8′	500
Pole (telephone)	7″ × 30′	60
Pole	9″ × 30′	100
Pile	7″ × 30′	60
Stull	10″ × 16′	60
Tie (standard)	6″ × 8″ × 8′	30
Tie (second class)	6″ × 7″ × 8′	20
Tie (narrow gauge)	6″ × 7″ × 6′	15
Tie	7″ × 8″ × 8′	30
Tie	7″ × 9″ × 8′	35
Cubic foot (round)	.....	6
Post	6″ × 7′	7
Post (circumference 18 inches)	5.7″ × 7′	6
Post	5″ × 7′	5
Linear foot	10″ × 1′	3

(*b*) *Cubic Feet.*—The cubic foot measure, or actual volume, is rarely used commercially in this country, athough in many foreign countries the log scale is based on the cubical content of the log.

In the United States the cubic foot is used chiefly for logs which are not to be cut into lumber, as pulpwood, excelsior wood, rotary-cut veneer stock, high priced vehicle woods, red cedar pencil stock, and imported timber, although all of these are also sold by the cord.

In converting the cubic contents of round logs into board feet it is customary to consider 1 cubic foot equal to 5 board feet, although the ratio varies with the diameter of the timber as can be seen from Fig. 125,[1] which shows the number of board

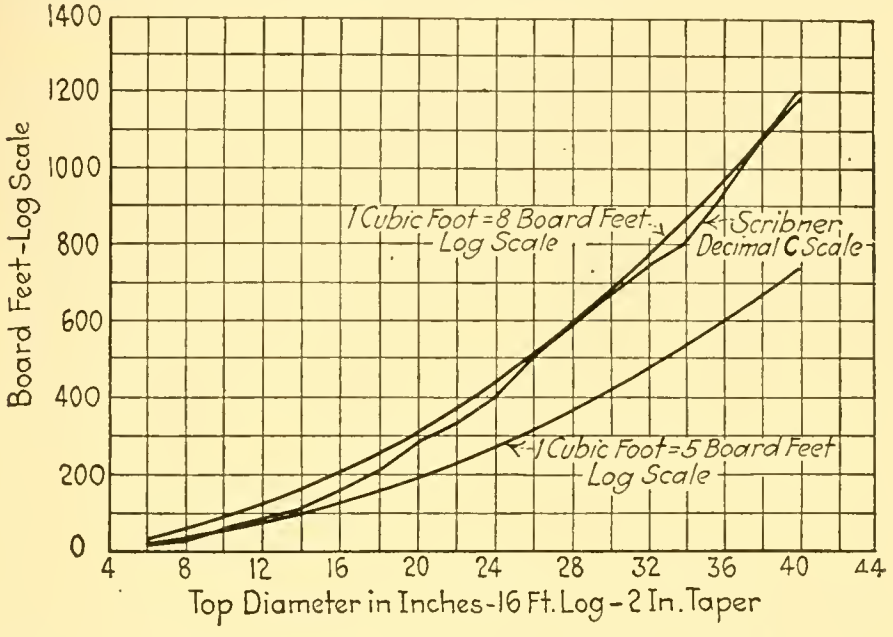

FIG. 125.—Relation of board feet to diameter of logs according to the Scribner Decimal C rule and according to calculations based on 5 and 8 board feet per cubic foot of total volume. (*Data by Forest Products Laboratory.*)

feet in 16-foot logs of various diameters according to the Scribner Decimal C log scale, and as calculated on a basis of 5 board feet and 8 board feet respectively per cubic foot. In small logs the log scale corresponds approximately to 5 board feet per cubic foot, but in large logs as high as 8 board feet can be obtained per cubic foot. Imported timbers are usually squared which makes the waste less, and, therefore, a converting factor of 8 board feet per cubic foot gives a fair average.

(*c*) *Cord Measure.*—The cord measure is used for firewood, pulpwood, excelsior wood, extract wood, bolts and billets for shingles, spokes, handles, and occasionally for small saw logs.

[1] Taken from a paper: WINSLOW, C. P. and THELEN, ROLF, "The Purchase of Pulpwood," read before the Technical Association of the Pulp and Paper Industry, New York, Sept. 28, 1918.

A cord of wood is a stack 4 feet high, 4 feet wide, and 8 feet long, and contains 128 cubic feet. In some localities a long cord 4 by 5 by 8 feet is used, as in the case of extract and handle stock. Short cords are often used in measuring firewood, the common length being 16 inches, which amounts to a third of a standard cord when piled 4 feet high and 8 feet long. Other lengths may also be used. Wood for distillation purposes is cut 50 inches long.

The solid contents of a cord of wood may vary from less than 60 to rarely over 102 cubic feet, depending upon the size and

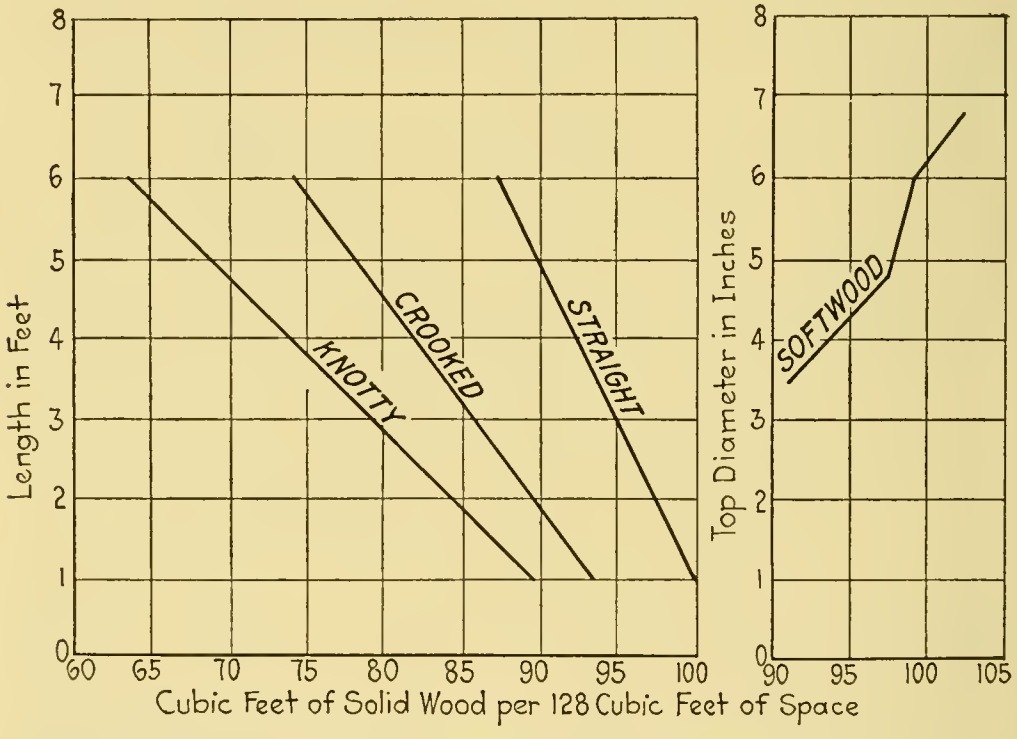

FIG. 126.—Relation of length, diameter, and straightness of pieces to cubic contents of solid wood per cord measure.

straightness of the sticks, 85 cubic feet per cord being a fair average. The relation of solid wood per cord to length and diameter of the sticks is shown in Fig. 126. A cord of green wood does not measure a full cord when seasoned. Therefore, it is customary to pile green wood 2 or 3 inches higher than is required so as to allow for shrinkage. To get the greatest amount of wood per cord one should select a heavy kind which is well seasoned, straight, cut into short lengths but of as large a diameter as possible, and compactly piled Unless the wood is used for fuel, it is also desirable to have it peeled.

In converting cord measure to board feet, as is sometimes desirable for pulpwood and excelsior wood, it is customary to consider one cord the equivalent of 500 board feet, although the actual equivalent varies more or less depending upon the nature of the material.

(*d*) *Linear Feet.*—This unit is used for such rough products as poles, piling, mine timbers, and rafters, a certain maximum and minimum top diameter being specified or understood. Among manufactured products mouldings are the chief article sold by the linear foot.

(*e*) *Pieces.*—Ties, posts, spokes, handles, lath, shingles, barrel staves, heading, hoop poles, pencil slats, and numerous other wooden products including some electric-wire poles, piling, and mine timbers are sold by the piece, or by the package containing a definite number of pieces.

(*f*) *Surface Measure.*—Lumber less than $\frac{3}{16}$ inch thick, such as box boards and veneers, is sold by the surface measure.

CHAPTER XIV

COMMERCIAL GRADING AND STANDARD SIZES OF LUMBER

Lumber is classified not only as to the kinds or species of wood but also as to the quality or grade of the same kind. The grading of lumber is based on the character, number, and location of defects it contains and to a certain extent on the size of the boards. The better grades of lumber are comparatively free from defects and are limited as to the percentage of small boards they may contain, while the lower grades have so many defects that only small-sized clear pieces can be cut from them, or, if the lumber is used entire, it is fit only for very cheap or temporary construction.

The purpose of grading lumber is to make it possible for different manufacturers of the same kind of lumber to put on the market grades approximately equal in value. The grading of lumber is also of advantage to the consumer, as he can order a standard quality which meets his needs instead of buying a mixture of clear and defective lumber as it comes from the log, or "log run" as it is called.[1]

116. The Development of Grading.—

In the early days of the lumber industry in this country there were practically no standards of quality, called grades. There was a standard of quantity or scale, but it was not until later that the need for a measure of quality was felt. The present systems of grading lumber are the result of a gradual growth and evolution. Owing to the changing conditions of production and consumption, it has not been possible to devise an absolutely fixed system. Slight variations must be expected, but the tendency is to become more and more stable as the conditions are more thoroughly understood.

Lumber was first sold either "log run" or "log run, culls out." It was measured, but the relative quality was not determined. The dealer, however, separated his purchase into two or three different lots based

[1] For more detailed information on lumber grades the reader is referred to the grading rules of the various lumber associations, and to United States Department of Agriculture *Circular* **64**, "How Lumber is Graded" by H. S. Betts.

on quality, and in a way graded his lumber. This practice gradually grew until it crystallized into specific rules for certain of the leading markets. One of the earliest markets where grading was practiced was Bangor, Maine; later it was taken up at Albany, New York, and at Port Deposit, Maryland.

At all these points inspection was made by the dealer or an official inspector, either of the State, county, or city. For many years at the great centers of distribution, inspection was carried on in this way. The producer shipped his lumber to the dealers, who, as the demand became more and more specialized, divided it into gradually increasing numbers of grades. It was not until the early eighties that any attempt was made by the producer of lumber to grade his own product before shipping.

White pine was one of the first species to be graded, as it was among the first to be lumbered. In 1833 the State of Maine passed a law for the inspection of lumber in Penobscot County. Grades were defined by this law for white pine as well as for hemlock, spruce, and cedar.

Uniform producers' grades were initiated in the white pine region and in the South at three different points at practically the same time. The system of organized inspection by associations was originated in the Lake Region. The Wisconsin Valley Association was the first to have it. But it was not until 1895 that a system of inspection was organized covering a large area. In this year the Mississippi Valley Lumbermen's Association organized a complete system of inspection which has been largely copied by other associations. This system has met with remarkable success in keeping the grades uniform throughout the territory covered. The region covered by the inspection is divided into districts, and an inspector is assigned to each. Once a year, at least, all the inspectors meet and compare notes, and so keep their ideas uniform.[1]

In 1906 the Wisconsin Valley Lumbermen's Association and the Mississippi Valley Lumbermen's Association merged into the Northern Pine Manufacturers' Association. The grading rules of this association were made by the manufacturers, and, consequently, were fairly satisfactory and widely used.

In the earlier history of lumber grading a few grades sufficed. A farmer in building a barn bought sound-knotted and clear stock which, if it had been given a name, would have been called "merchantable"; whereas an industrial plant bought loose-knotted and otherwise defective or "cull" lumber for boxing and crating purposes.

[1] Hodson, E. R., "Rules and Specifications for the Grading of Lumber Adopted by the Various Lumber Associations of the United States." Forest Service *Bulletin* **71**, 1906.

As manufacturing became more and more diversified a demand for special grades of lumber sprung up. A factory making window sash and doors demanded lumber which would furnish clear cuttings. If lumber with large knots or knot holes and long, wide, clear spaces between the knots could be purchased enough cheaper than clear lumber to make its use profitable so much the better. The farmer on the other hand preferred the small knotted, water-tight board to lumber with large knots or knot holes. A wagon manufacturer preferred a still different grade of lumber, and so on.

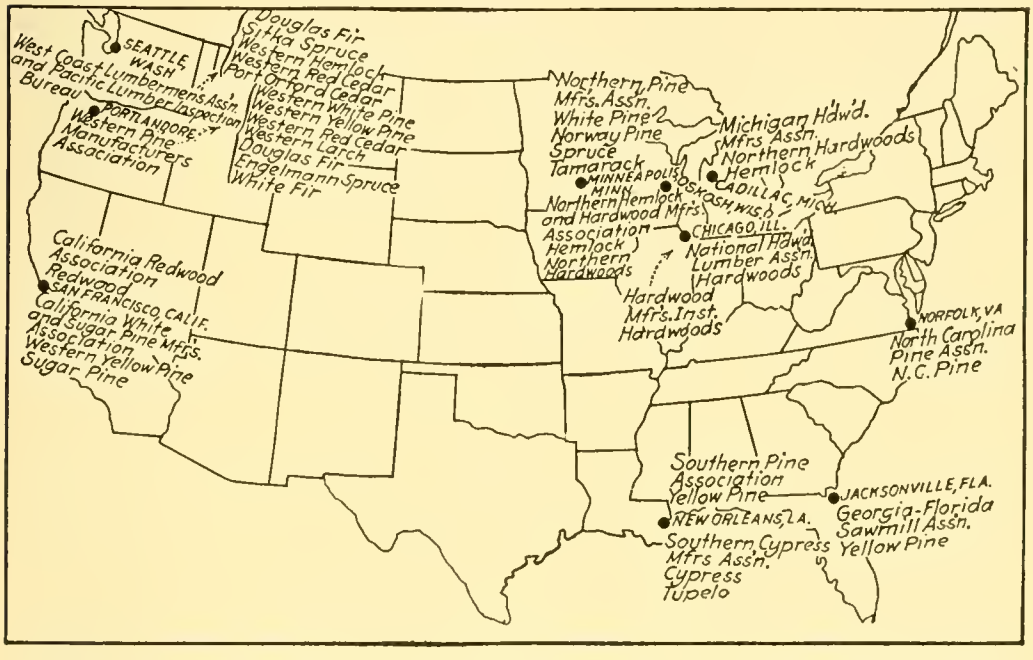

FIG. 127.—The principal lumber manufacturers associations showing headquarters and woods covered by grading rules.

For the purpose of supplying these various demands for different types of lumber, the progressive manufacturers of the northern states made a large number of segregations of these various types, or, in other words, grades of lumber. On account of the many different uses of lumber it was impossible to make a grade of lumber for each specific use, so types or grades were segregated for their particular working relationship to certain classes of products. While the northern associations developed their rules, associations of lumbermen in other parts of the country, manufacturing different kinds of lumber, also promulgated rules intended to suit their particular needs. At the present time there are over a dozen active lumber associations in the United States. Each association confines grading to the particu-

lar kinds of lumber it handles, although several kinds of lumber are graded by two or more associations.

The following are the names and headquarters of the principal lumber associations which have grading rules, and the kinds of woods covered by their rules. Figure 127 shows the location of the headquarters of the lumber manufacturers' associations:

1. Northern Hemlock and Hardwood Manufacturers' Association, Oshkosh, Wisconsin—Hemlock and hardwoods. (Hardwood rules same as for National Hardwood Lumber Association.)
2. Northern Pine Manufacturers' Association, Minneapolis, Minnesota—White pine, Norway pine, spruce, and tamarack.
3. Michigan Hardwood Manufacturers' Association, Cadillac, Michigan—Hemlock and hardwoods. (Hardwood rules same as for National Hardwood Lumber Association.)
4. White Pine Association of the Tonawandas, North Tonawanda, New York—White pine.
5. North Carolina Pine Association, Norfolk, Virginia—Yellow pine lumber of Maryland, Virginia, North Carolina, and South Carolina.
6. Georgia-Florida Sawmill Association, Jacksonville, Florida—Southern yellow pine.
7. Southern Pine Association, New Orleans, Louisiana—Southern yellow pine.
8. Southern Cypress Manufacturers' Association, New Orleans, Louisiana—Cypress and tupelo.
9. Western Pine Manufacturers' Association, Portland, Oregon—Western white pine, western yellow pine, larch, Douglas fir, Engelmann spruce, white fir, and western red cedar.
10. West Coast Lumbermen's Association, Seattle, Washington—Douglas fir, Sitka spruce, western red cedar, Port Orford cedar, and hemlock.
11. Pacific Lumber Inspection Bureau, Seattle, Washington—Douglas fir, Sitka spruce, western red cedar, Port Orford cedar, and hemlock.
12. California White and Sugar Pine Association, San Francisco, California—Sugar pine and western yellow pine.
13. California Redwood Association, San Francisco, California—Redwood
14. National Hardwood Lumber Association, Chicago, Illinois—Hardwoods and cypress.
15. Hardwood Manufacturers' Institute, Memphis, Tennessee—Hardwoods and cypress.

117. Defects Which Lower the Grade of Lumber.—Defects in lumber are faults which seriously detract from its strength, appearance, or other useful properties when the lumber is to be used for certain purposes. For other uses of the lumber the defects may not be a serious drawback. For example, several small knots may be objectionable in a door casing but not in a scantling; or discolored sapwood may make a board unfit for

exposed parts of furniture, but not for the cores of veneered panels.

Defects may be due to natural causes which cannot be prevented, or to careless manufacturing and seasoning, much of which can be avoided. The nature of the defects varies with the kind of lumber, the age and history of the stand, and the locality

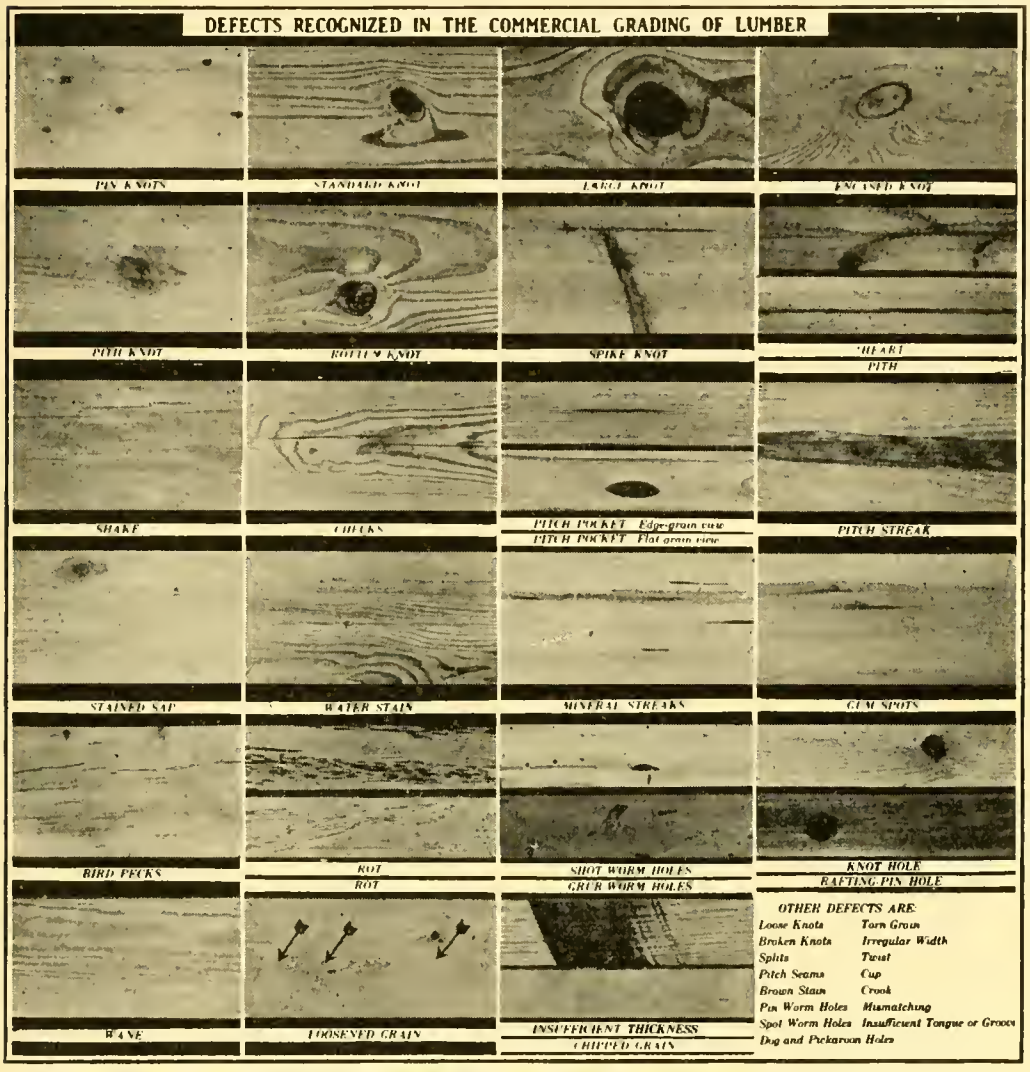

FIG. 128.—Defects in lumber. (*Courtesy, Forest Products Laboratory.*)

of growth. Gum spots are peculiar to mahogany and cherry; pitch streaks occur only in the pines, spruces, Douglas fir, and tamaracks; mineral streaks are common in maple, basswood, and hickory, but rare in other species. Old trees have more loose knots and rot than young trees. Fire scars may be common in timber from stands which have been burned over several times.

In certain localities the timber is larger and straighter than in others, thus producing wider and clearer boards.

The following are some of the more common recognized defects which may occur in boards and dimension stock and lower their grade. Figure 128 illustrates some of these defects as found in lumber.

Knots are classified as to size, form, and quality as follows:[1]

A *pin knot* is less than ½ inch in diameter.

A *standard knot* is from ½ inch to 1½ inches in diameter.

A *large knot* is over 1½ inches in diameter.

A *round knot* is circular or oval in form.

A *spike knot* is one cut through lengthwise, and, therefore, can occur in quarter-sawed or edge-grain lumber only.

A *sound knot* is as hard as the wood it is in, and its fiber is intergrown more or less with the surrounding wood.

An *encased knot* is one not firmly connected throughout with the surrounding wood, but is firmly held in position so it will not drop out.

A *loose knot* is one not firmly held in position.

A *rotten knot* is one not so hard as the wood it is in.

Shake is a partial or entire separation of two annual rings. It is believed to be caused by the trees swaying back and forth in the wind, and for this reason is also known as "wind shake." On account of its circular form it is also known as "cup shake" and "round shake." It is common in hemlock, sycamore, western larch, and a few other species, and may occur in any species.

Checks are splits which run radially across the rings and are usually due to uneven shrinkage in seasoning. Radial checks may extend outward from the pith for several inches in green timber. These are known as "star shake."

Splits are due to rough handling or internal stresses, and are easily confused with checks and shakes.

Pitch pockets are lens-shaped openings in the annual rings containing more or less resin. They are found only in the pines, spruces, Douglas fir, and larch or tamarack.

Pitch streaks are accumulations of pitch in the wood cells.

[1] The definitions of knots as here given are not universally accepted. For example, a standard knot according to the West Coast Lumbermen's Association rules is from ¾ to 1½ inches in diameter; under the rules of the Southern Cypress Manufacturers' Association a standard knot is from ¾ to 1¼ inches in diameter; and according to the National Hardwood Lumber Association a knot 1¼ inches in diameter is considered a standard defect. Nor are these definitions entirely in accord with the proposed standard specifications of the Forest Service for yard lumber which state that a *pin knot* is one not over ⅜ inch in diameter; a *small knot* is one over ⅜ but not more than ¾ inch in diameter; a *medium knot* is one over ¾ but not more than 1½ inch in diameter; and a *large knot* is one over 1½ inches in diameter.

Wane is bark on the edge of a piece or the absence of the square edge.

Rot and dote are different stages of decay. "Red heart," a form of decay often found in pines, Douglas firs, spruces, and some other conifers, is not considered a defect in the lower grades of lumber if the wood is still fairly firm.

Stain is a discoloration which affects only the appearance of the lumber and usually is permissible in the lower grades. Stains are classified as blue stain, brown stain, water stain, sticker stain, etc.

Mineral streaks are not clearly defined. They may be only discolored streaks in sound wood, or they may be a deposit of mineral matter, as near bird pecks in hickory.

Pith is the small soft core at the structural center of a log. It is often surrounded by small checks, shakes, and pin knots.

Worm holes are the passageways made by grubs or beetles. They are very common in some woods and may render them unfit for high-grade work. They may be small, in which case they are known as pin wormholes, or, if in groups, shot wormholes; or they may be large, in which case they are known as grub wormholes.

Bird pecks and *gum spots* are small brown or black discolorations. Sometimes they contain cavities, which, in the case of gum spots, are filled with gum.

Rafting-pin holes are holes bored for rafting pins, or holes made by rafting pins driven into logs.

Crook is a longitudinal curvature edgewise.

Bow is a longitudinal curvature flatwise.

Twist is a turning or winding of the edges of a piece so that the four corners of a face are no longer in the same plane.

Cup is the curving of a piece across the grain or width of a piece.

Poor manufacture includes irregular width or thickness, chipped or torn grain, and other faults of manufacture.

These defects are not considered equally serious in the different kinds of lumber. That is, what is considered a defect in one species may not be considered so serious a defect in another species. The number of defects permitted in lumber of a certain grade varies with the size of the pieces, so that in very large pieces of even the best grades occasional defects may be found.

Lumber is graded according to the appearance of the poorer side if both sides are going to show, or according to the appearance of the better side, if only one side is going to show. In door and sash stock, for instance, both sides can be seen in the finished product, while in furniture and interior trim only one side can be seen.

118. Grades.—Under modern systems of grading, lumber is divided into a great number of grades so as to suit all possible needs. Numerous grades exist for general building and construction in which the lumber is used with the defects in it. Other

grades are designed for special purposes for which the lumber must be cut up, and the defects may be largely or entirely eliminated, as for furniture, sash and doors, flooring, wagons, and packing boxes. The diversity in grading is so great that only one who constantly handles lumber can expect to be familiar with most of the grades of a certain kind of wood. It is an advantage to the consumer, however, to become familiar with the names, quality, and prices of the grades he may want to use so that he can select the most suitable kind and guard against unscrupulous dealers delivering a lower grade than was ordered.

Table XXXIV gives the names of the principal grades of lumber used for finishing and other high-class work, and of the lower grades used for general construction. It will be noticed that the different lumber associations do not apply the same name to the best, second best, etc., grades respectively. Furthermore, the best, next best, etc. grades are not always of the same quality, that is, they are not limited in the same manner as to the character of defects they contain. This condition causes more or less confusion in the marketing of lumber, and leads engineers and architects occasionally to specify other materials for which the grading is less diversified.

In some markets two or more grades are combined into one, as Clears and Selects, B and better (written B and B), First and Seconds (written FAS or F & S), and No. 1 and No. 2 Common, because not sufficient material of the better grades is cut to make its separate classification practicable. In such combinations a certain specified per cent of the upper grades must be present.

Tables XXXV and XXXVI give brief descriptions of standard grades of eastern white pine and hardwoods. By carefully reading these descriptions the character of each grade and the differences between grades can be ascertained. The standard grade classification for hardwoods is modified slightly for each species of lumber. The percentage of Firsts in Firsts and Seconds combined also varies with the kind of lumber. For more detailed information on lumber grades the reader is referred to the grading rules of the various lumber associations.

TABLE XXXIV

COMPARISON OF FOREST SERVICE BASIC GRADES FOR SOFTWOOD YARD LUMBER AND GRADES OF THE PRINCIPAL MANUFACTURERS' ASSOCIATIONS

BASED ON DEFECTS PERMITTED IN EACH GRADE AS SHOWN IN PUBLISHED GRADING RULES

	BASIC GRADES PROPOSED BY THE FOREST SERVICE	NORTHERN PINE MANUFACTURERS ASSOCIATION	WESTERN PINE MANUFACTURERS ASSOCIATION	CALIFORNIA WHITE & SUGAR PINE MFRS ASSOCIATION	WEST COAST LUMBERMENS ASSOCIATION	SOUTHERN PINE ASSOCIATION	GEORGIA-FLORIDA SAWMILL ASSOCIATION	NORTH CAROLINA PINE ASSOCIATION	SOUTHERN CYPRESS MFRS ASSOCIATION	CALIFORNIA REDWOOD ASSOCIATION	NORTHERN HEMLOCK AND HARDWOOD MFRS ASSOCIATION	MICHIGAN HARDWOOD MFRS ASSOCIATION
SELECT GRADES — SUITABLE FOR NATURAL FINISHES	GRADE A Practically free from all defects	1 CLEAR 2 CLEAR 3 CLEAR A SELECT	B SELECT AND BETTER	NO 1 AND 2 CLEAR	SELECTED FLAT GRAIN	A FINISHING	A FINISHING	NO 2 AND BETTER	CLEAR HEART A	CLEAR SAP CLEAR	INCH CLEAR AND SELECTS	C AND BETTER
	GRADE B Allows a few small defects or blemishes	B SELECT		C SELECT	NO. 2 CLEAR	B FINISHING	B FINISHING		B	SELECT		
SELECT GRADES — SUITABLE FOR PAINT FINISHES	GRADE C Allows a limited number of small defects and blemishes that can be covered by paint	C SELECT	C SELECT		NO 3 CLEAR	SELECT COMMON FINISHING	C FINISHING	NO 3	C	STANDARD		
	GRADE D Allows any number of defects or blemishes which do not detract from a finish appearance especially when painted	D SELECT D STOCK AND BOX	D SELECT	D SELECT	SELECT COMMON USUALLY MIX NO 1 COMMON	NO 1 COMMON	NO 1 COMMON		D	EXTRA MER. CHANTABLE	INCH D STOCK	NO 1 COMMON
COMMON GRADES — SUITABLE FOR USE WITHOUT WASTE	NO 1 COMMON Sound and tight knotted stock use of defects and blemishes limited May be considered water-tight lumber	NO 1 COMMON	NO 1 COMMON	NO 1 COMMON	NO 1 COMMON			NO 1 BOX	NO 1 COMMON		INCH NO 1 COMMON	NO 2 COMMON
	NO 2 COMMON Allows large and coarse defects May be considered grain-tight lumber	NO 2 COMMON	NO 2 COMMON	NO 2 COMMON	NO 2 COMMON	NO 2 COMMON	NO 2 COMMON		NO 2 COMMON	CON-STRUCTION	INCH NO 2 COMMON	NO 3 COMMON
COMMON GRADES — PERMITTING SOME WASTE IN USE	NO 3 COMMON Allows larger and coarser defects than No 2 and occasional knot holes · 75% as good as No 2	NO 3 COMMON	NO 3 COMMON	NO 3 COMMON	NO 3 COMMON	NO 3 COMMON	NO 3 COMMON	NO 2 BOX	NO 3 COMMON	NO 3 ONLY LOCALLY RECOGNIZED		NO 4 COMMON
	NO 4 COMMON Low quality lumber containing the coarsest defects such as rot and holes · 50% as good as No 2 common	NO 4 COMMON	NO 4 COMMON	NO 4 COMMON	CULLS ONLY LOCALLY RECOGNIZED	NO 4 COMMON	NO 4 COMMON	RED HEART BARK STRIPS	BOX "PECKY" CYPRESS		INCH NO 3 COMMON	NO 5 COMMON
	NO 5 COMMON Must hold together under ordinary handling	NO 5 COMMON	NO 5 COMMON	NO 5 COMMON							INCH NO 4 COMMON	

TABLE XXXV.—DESCRIPTION OF WHITE PINE GRADES ACCORDING

Lengths allowed, feet	Widths allowed, inches	Defects allowed
GRADE—B SELECT AND BETTER		
6 to 20	4 and wider	In this grade white sap is not considered a defect unless too many other imperfections appear. Knots, shake, season checks, and a small amount of stained sap are admissible. A 4-inch or 6-inch piece should have but very little shake. Wider pieces can have more shake, but it should be local and not scattered over the face of the piece. Season checks equivalent to shake defects are admissible. Slightly stained sap is admissible when other defects are not of a serious nature, the amount of stained sap depending upon width of piece.
GRADE—C SELECT		
6 to 20	4 and wider	This grade will admit of quite serious defects if the piece retains at the same time a fair appearance. The defects admissible are the same as those in "B" Select, but exist to a greater degree. Medium blue stain covering one-third the face of the piece or surface season checks equivalent to shake defect are admissible if not in combination with other marked defects.
GRADE—D SELECT		
6 to 20	4 and wider	This grade admits any piece of lumber that has the appearance of finishing or a percentage of cutting in which the defects are too numerous or too serious to admit of its being graded into "C" Select. Medium blue stain covering entire face or season checks equivalent to shake defect will be admitted if not in combination with other marked defects. Above description embraces 1 inch or thicker stock and is graded strictly from the face without regard to the back and cannot be recommended for quality.
GRADE—NO. 1 COMMON BOARDS AND STRIPS		
6 to 20	8 and wider	No. 1 Common Boards and Strips includes all sound, tight-knotted stock, whether red or black knots, free from very large, coarse knots, or any imperfections that will weaken the piece. This grade should be of a character fitting it for ordinary use, except finishing purposes. Knots, medium colored blue sap, or a small amount of shake are admissible if they do not affect the general utility of the piece.

TO RULES OF THE NORTHERN PINE MANUFACTURERS' ASSOCIATION[a]

GRADE—NO. 2 COMMON BOARDS AND STRIPS		
6 to 20	8 and wider	No. 2 Boards and Strips are subject to the same general inspection as No. 1 except that coarser and larger knots, not necessarily sound, and more stained sap and shake are allowed. "V" and coarse limb knots, heart shake or slight trace of rot, when firm, or occasional worm holes, are defects admissible in this grade.
GRADE—NO. 3 COMMON BOARDS AND STRIPS		
6 to 20	4 and wider	The general appearance of this grade of lumber is coarse, admitting: Large, loose, or unsound knots An occasional knot hole. A great deal of shake. Some red rot. Large worm holes. Any amount of blue sap. A serious combination of these defects in any one piece is not admissible.
GRADE—NO. 4 BOARDS AND STRIPS		
6 to 20	4 and wider	The predominating defect characterizing this grade is red rot. Other types are pieces showing numerous large worm holes, or several knot holes, or pieces that are extremely coarse knotted, wany, shaky, or badly split. Pieces, when extremely cross checked, are not admissible in this grade.
GRADE—NO. 5 BOARDS		
6 and longer	4 and wider	This is the lowest recognized grade and admits of all defects known in lumber, provided the piece is strong enough to hold together when carefully handled.

[a] Lengths and widths as in "Classified Recommended Uses for White Pine in House Construction and White Pine Standard Grading Rules," White Pine Bureau, 1917. Defects as in 1924 rules.

TABLE XXXVI.—DESCRIPTION OF STANDARD HARDWOOD GRADES ACCORDING TO RULES OF NATIONAL HARDWOOD LUMBER ASSOCIATION[a]

(Inspection to be made on the poor side of the piece)

GRADE—FIRSTS

Lengths allowed, feet	Widths allowed, inches	Defects allowed
8 to 16 (Not over 20 per cent under 12 feet and not over 10 per cent 8 and 9 foot lengths in Firsts and Seconds combined)	6 and wider	Ranging from no defects in pieces 4 to 9 square feet surface measure to two standard defects in pieces of 16 square feet and over surface measure.

GRADE—SECONDS

8 to 16 (See note under firsts)	6 and wider	Ranging from one standard defect in pieces 5 square feet surface measure to five standard defects in pieces 20 square feet surface measure.

GRADE—SELECTS

6 to 16 (Not over 30 per cent under 12 and not over 5 per cent of 6 and 7 foot lengths.)	4 and wider	Ranging from no defects on one side of piece 6 and 7 feet long with reverse side not below No. 1 Common to pieces 7 inches and wider and 10 feet and longer with defects that do not cause a waste of more than 1 inch in width for the full length or its equivalent on one or both ends with reverse side not below No. 1 Common.

GRADE—NO. 1 COMMON

4 to 16 (Not over 10 per cent of 4 to 7 foot lengths.)	3 and wider (Not over 5 per cent of 3 inch widths)	Ranging from no defects in pieces 4 and 5 feet long to pieces 8 inches and wider and 14 feet and longer that will cut 66⅔ per cent clear face in four cuttings. (No cutting less than 4 inches by 2 feet or 3 inches by 3 feet.)

GRADE—NO. 2 COMMON

4 to 16 (Not over 10 per cent of 4 and 5 foot lengths.)	3 and wider	Ranging from pieces 3 to 7 inches wide and 4 to 10 feet long that cut 50 per cent clear face in 3 cuttings to pieces 8 inches and wider and 14 feet and longer that cut 50 per cent cle r face in five cuttings. (No cutting less than 3 inches by 2 feet.)

GRADE—NO. 3 COMMON

4 to 16	3 and wider	Pieces must contain at least 25 per cent sound cuttings. (No cutting less than 1½ inches wide or 36 square inches surface measure.)

[a] From Association rules dated Sept., 1923. See original rules for more detail.

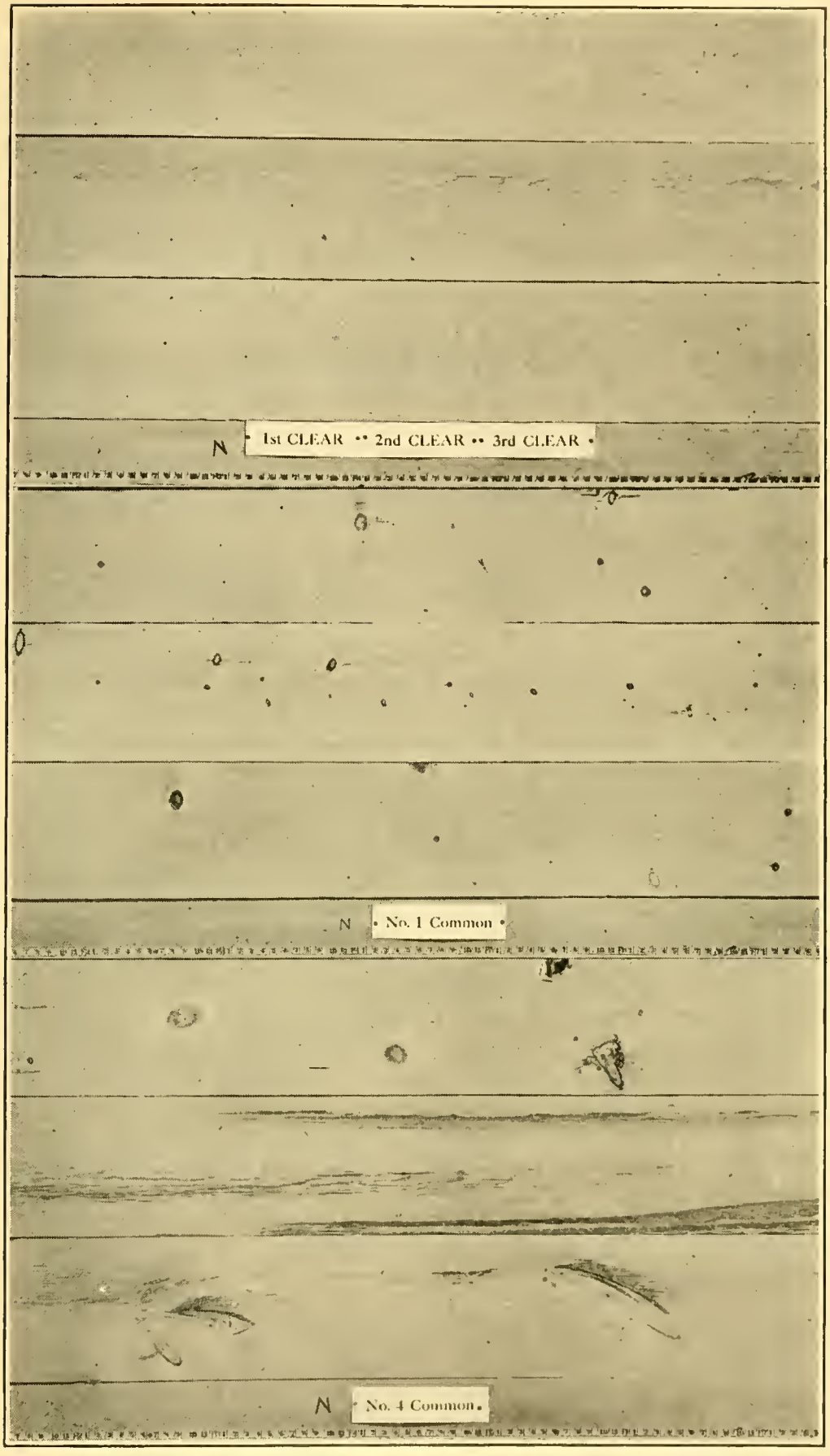

FIG. 129.—Typical boards of first, second, and third Clears, No. 1 Common; and No. 4 Common white pine according to the Northern Pine Manufacturers Association. (*Courtesy, White Pine Bureau, St. Paul.*)

A few examples of the character and uses of various grades will help to make plain the advantage of grading.

White pine Clears (Fig. 129) are suitable where the very highest type of white pine is desired, as for interior and exterior finish, panels, and enameled work. A and B Selects can be used for the same purposes and are only slightly inferior. In fact all the three Clear grades and A and B Selects are usually sold as one grade known as "B Select and Better," and can be obtained separately only on special order.[1]

C and D Selects of white pine are suitable for the trim of houses of medium and low cost, and for the making of cabinets, mouldings, and other mill work.

Nos. 1 and 2 white pine Fencing dressed and matched (D & M) is used for flooring which is to be covered, lining, sheathing, partitions in basements, sub-floors, and roof boards.

No. 1 Common white pine (Fig. 129) is suitable for many purposes where sound tight knots of medium size are not objectionable, as for lining, roof boards, barn siding, and flooring of low quality. No. 2 Common contains more and larger knots not necessarily sound. More stain and shake are allowed, and slight traces of rot, if firm. It is used for the same purposes as No. 1 whenever slightly lower quality is permitted.

Nos. 3 and 4 Common white pine (Fig. 129) are still coarser and used mainly when covered, as for sheathing, sub-floors, and roof boards. No. 5 Common is the lowest grade and suitable only for the very cheapest or temporary construction.

Firsts and Seconds of birch are sold together as one grade, and are used for furniture, interior finish, doors, and other high-grade work requiring clear lumber in fairly large sizes.

Birch Selects are used for the same purposes as Firsts and Seconds, whenever smaller sizes can be utilized.

Nos. 1 and 2 Common birch are used for furniture and interior finish of a lower quality or where still smaller sizes can be used, and for flooring.

No. 3 Common birch is used for crating, grain doors, cheap construction work, etc.

No. 4 Common birch is used for very cheap and temporary work.

[1] "Classified Recommended Uses of White Pine and White Pine Standard Grading Rules," published by the White Pine Bureau, St. Paul, Minnesota, 1917.

119. Standard Sizes.—Lumber is usually cut into standard lengths, widths, and thicknesses in accordance with the grading rules of the various lumber associations. This is of inestimable value in the storing and use of boards and dimension stock. In European countries and the New England States lumber is often marketed without being edged, that is, without removing the bark or making the sides parallel. While this saves lumber it adds more or less to the cost of subsequent manufacture.

Standard lengths for softwoods are 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 feet for common boards, shiplap, and dimension stock; and multiples of 1 foot from 4 to 20 feet inclusive for finishing lumber, flooring, ceiling, partition, siding, casing, base, molding, window sills, and door jambs.

Standard lengths are full measure, but the width and thickness of dressed lumber usually are less than the designated dimension. It, therefore, becomes necessary to distinguish between actual dimensions and nominal dimensions. The latter is the rough size required to manufacture the dressed stock, and is the dimension under which it is sold. The fact that the actual dimension is less than the nominal dimension must be taken into consideration in calculating the strength of studding, joists, and timbers; in calculating the thicknesss of floors and walls; and in figuring a bill of lumber for a structure of a certain size. Furthermore, the actual dimensions for a certain nominal size are not the same for all kinds of lumber as is shown for certain softwoods in Tables XXXVII, XXXVIII, XXXIX, and XL. These variations are due to the fact that the lumber is manufactured according to the grading rules of different associations.

Standard widths of softwood common lumber are in multiples of 1 inch from 3 inches up, as for southern yellow pine; or in multiples of 2 inches from 4 inches up, as for Douglas fir and hemlock. Widths of softwood finish lumber are in multiples of 1 or 2 inches from 4 inches up. An allowance of from $\frac{1}{4}$ to $\frac{3}{4}$ inch is made if both edges are dressed.

The standard thicknesses of softwood lumber are given in Table XL. This table shows that the thickness of dressed lumber depends in some cases on whether one or both sides are surfaced, and according to the association rules under which it is manufactured.

Hardwood standard lengths are in multiples of 1 foot from 4 to 20 feet inclusive, but not over 15 per cent of odd-

TABLE XXXVII.—NOMINAL AND ACTUAL SIZES OF SOFTWOOD TWO-INCH DIMENSION STOCK, SURFACED ON ONE SIDE AND ONE EDGE (S1S1E)

Nominal widths in inches	4	6	8	10	12	Actual thickness in inches
Actual width in inches for:						
Southern yellow pine (5, 6, 7)[a]	3⅝	5⅝	7½	9½	11½	1⅝
Douglas fir (10)	3⅝	5⅝	7½	9½	11½	1⅝
Cypress (8)	3⅝	5⅝	7½	9½	11½	1¾
Eastern hemlock (1, 3)	3¾	5¾	7¾	9¾	11¾	1¾
Northern pine (2)	3⅝	5⅝	7½	9½	11½	1⅝
Western pine (9)	3⅝	5½	7½	9½	11½	1⅝

[a] Figures refer to the numbers of the associations on page 324 which specify the actual sizes indicated in this table.

TABLE XXXVIII.—NOMINAL AND ACTUAL SIZES OF SOFTWOOD ONE-INCH SHIPLAP

Nominal widths in inches	8	10	12	Actual thickness in inches
Actual face width in inches for:				
Southern yellow pine (5, 6, 7)[a]	7⅛	9⅛	11⅛	¾
Douglas fir (10)	7	9	11	¾
Cypress (8)	7	9	11	13/16
Eastern hemlock (1)	7¼	9¼	11¼	25/32
Eastern hemlock (3)	7¼	9¼	11¼	13/16
Northern pine (2)	7	9	11	25/32
Western pine (9)	7	9	11	¾
Western pine (12)	7	9	11	13/16

[a] See footnote, Table XXXVII.

TABLE XXXIX.—NOMINAL AND ACTUAL SIZES OF SOFTWOOD ONE-INCH FLOORING

Nominal widths in inches	3	4	5	6	Actual thickness in inches
Actual face width in inches for:					
Southern yellow pine (5, 6, 7)[a]	2¼ or 2½	3¼	...	5¼	13/16
Douglas fir (10)	2¼	3¼	...	5⅛	13/16
Cypress (8)	2¼	3¼	4¼	5¼	13/16
Eastern hemlock (1)	...	3¼	...	5¼	25/32
Eastern hemlock (3)	...	3¼	...	5¼	13/16
Northern pine (2)	2¼	3¼	...	5¼	25/32
Western pine (9)	2¼	3¼	...	5¼	25/32
Western pine (12)	...	3¼	...	5¼	13/16

[a] See footnote, Table XXXVII.

TABLE XL.—NOMINAL AND ACTUAL THICKNESSES OF SOFTWOOD LUMBER SURFACED ON ONE OR TWO SIDES

Nominal thickness in inches	1	1¼	1½	2
Actual thickness in inches for:				
Southern yellow pine (5)[a]	13/16	1 1/16	1¼	1¾
Southern yellow pine (6)	13/16	1 1/16	1 5/16	1¾
Southern yellow pine (7)	13/16	1⅛	1⅜	1¾
Douglas fir (10)	¾	1 1/16	1 5/16	1¾
Cypress (8)	13/16	1⅛	1⅜	1¾
Eastern hemlock (1)	25/32	.....	.....	1⅝[b]
Eastern hemlock (3)	13/16	.....	.....	1¾
Northern pine (2)	25/32	1⅛	1⅜	1¾
Western pine (9)[c]	25/32	1⅛	1⅜	1¾
Western pine (12)[c]	13/16	1 5/32	1 13/32	1 25/32
Redwood (13)	13/16[d]	1 1/16[d]	1 5/16[d]	1¾

[a] See footnote, Table XXXVII.
[b] ⅛ inch thicker if S1S only.
[c] Thicknesses given for S2S only.
[d] 1/16 inch thicker if S1S only.

foot lengths are permissible; the remainder must be in even-foot lengths.

Standard widths for hardwoods run from 3 inches up in multiples of 1 inch, except flooring which may be narrower. Hardwood lumber is sawed in maximum possible widths, that is, in fractional inch widths but is measured to the nearest inch in width.

Standard thicknesses of hardwoods are given in Table XLI.

TABLE XLI.—STANDARD THICKNESSES OF HARDWOOD LUMBER ACCORDING TO THE NATIONAL HARDWOOD LUMBER ASSOCIATION

Thickness in inches, rough	Thickness in inches. Surfaced 2 sides (S2S)[a]	Thickness in inches, rough	Thickness in inches. Surfaced 2 sides (S2S)[a]
3/8	5/16	1 3/4	1 1/2
1/2	7/16	2	1 3/4
5/8	9/16	2 1/2	2 1/4
3/4	13/16	3	2 3/4
1	1 3/32	3 1/2	3 1/4
1 1/4	1 11/32	4	3 3/4
1 1/2			

[a] Stock dressed on one side only is to surface 1/16 inch scant.

Since the standard dimensions of lumber are dictated by the various lumber associations, the dimensions, like the grading rules, differ and are subject to change from time to time. Dimensions which are accepted as standard now may not be standard 5 years from now. There seems to be a trend toward unification of standard dimensions, but movements in this direction have made slow progress. It is self-evident that the present variations in standard sizes of dressed lumber of the same nominal size cannot help but cause more or less confusion to the user of wood.

120. Standard Grading Specifications Proposed by the Government.—In order to eliminate the waste and inconvenience that result from comparable grades not being identical in name and quality, and finished sizes not being uniform, the Forest Products Laboratory of the U. S. Forest Service has proposed standard grading rules for structural timbers and yard lumber which are to be the same throughout the country and applicable

to all species. A study for the purpose of standardizing of factory softwood and hardwood lumber is also being made.

The new grading rules for structural timbers are given in Art. **43.** A summary of the basic grades for yard lumber and how they compare with existing grades is shown in Table XXXIV. The following is a description of the proposed basic grades. These are further limited as to size, grain (flat or edge), pattern, and special requirements so as to be applicable to finishing boards, flooring, casing, partition, molding, dimension, etc.[1] The recommended sizes for yard lumber are given in Table XLII.

SELECT GRADES

Lumber which is generally clear, containing defects limited both as to size and number, and which is smoothly finished and suitable for use as a whole for finishing purposes or other uses in which large clear pieces are required, shall be considered as Select lumber.

Two classes shall be recognized. The first shall be suitable for natural finishes. Defects and blemishes permitted in this class must be localized in nature. The second class permits similar defects and, in addition, blemishes of somewhat greater extent than those of the first class, but of a type which can be covered by paint.

These grades are based on a piece 8 inches wide by 12 feet long, or a piece which contains 8 square feet, surface measure.

Grade names: A, B, C, and D.

Grade A

Grade A shall be free from defects on the face side of pieces up to and including 12 inches in width. Widths greater than 12 inches will admit two or combination of two of any of the following defects:

Sound and tight pin knot.
Small pitch pocket.
Small surface check.
Slight crook.
Slight wane.
Bird's-eye.

[1] For details see Ivory, E. P., White, D. G., and Upson, A. T., "Standard Grading Specifications for Yard Lumber." United States Department of Agriculture *Circular* 296.

Grade B

Grade B shall possess natural finishing qualities, but will admit two or combination of two of any of the following defects:

Short split.
Fine shake—equal in length to width of piece.
Three small surface checks.
Medium wane.
Small crook.
Slight cup.
Medium sound and intergrown knot.
Three sound and tight pin knots.
Small pitch pocket.
Three very small pitch pockets.
Small pitch streak.
Pin wormholes—one per surface foot.
Light discoloration—5 per cent of area.
Firm red heart—5 per cent of area.
Patch slight torn grain.
Chipped grain.
Bird's-eye.

Grade C

Grade C shall possess finishing qualities, but will admit any four or combination of four of any of the following defects:

Short split.
Fine shake—equal in length to width of piece.
Three small surface checks.
Medium wane.
Small crook.
Slight cup.
Medium sound and intergrown knot.
Small encased knot.
Three sound and tight pin knots.
Small pitch pocket.
Three very small pitch pockets.
Medium pitch streak.
Pin wormholes—two per surface foot.
Medium discoloration—10 per cent of area.
Firm red heart—10 per cent of area.
Pith—3 inches in length.
Patch medium torn grain.
Slight skip.
Bird's-eye.

Grade D

Grade D shall be of Select Common quality and possess a finishing appearance, but will admit any number of the following defects and blemishes. More serious defects shall be permitted on the reverse side, but no combination so serious as to prevent its use for the purpose intended:

Short split.
Fine shake.
Medium surface check.
Medium wane.
Small crook.
Slight cup.
Medium sound and intergrown knot.
Small encased knot.
Pin knot.
Medium pitch pocket.
Medium pitch streak.
Pin wormholes—two per surface foot.
Medium discoloration—10 per cent of area.
Firm red heart—10 per cent of area.
Pith—3 inches in length.
Patch medium torn grain.
Slight skip.
Bird's-eye.

Pieces containing one serious defect, such as a loose knot or knot hole not more than 2 inches in diameter located more than 32 inches from either end, may be permitted, provided the rest of the piece is of B or better quality.

COMMON LUMBER

Lumber containing numerous defects and blemishes which preclude it from use for finishing purposes, but which is suitable for general utility and construction purposes, shall be considered common lumber.

Two general classes shall be recognized. The first shall be suitable for use as a whole for purposes in which surface covering or strength is required. Defects and blemishes permitted in this class must be sound. The second class permits very coarse defects which may cause waste in the use of the piece.

Grade names: No. 1 Common, No. 2 Common, No. 3 Common, No. 4 Common, and No. 5 Common.

No. 1. Common

No. 1 Common shall present a generally smooth appearance and be high-class general utility lumber. It permits any number of the following defects not in serious combination:

Sound and intergrown knots—1½ inches in diameter in 4-inch and 6-inch widths, 2 inches in 8-inch and 10-inch, 2½ inches in 12-inch, and not over 3 inches in wider widths.

Black and encased knots—one-half the diameter of sound and intergrown knots permitted up to a maximum diameter of 1¼ inches, provided the knot be sound and immovably fixed in position.

Short split.

Slight shake that does not go through, equal in length to width of piece.

Surface checks.

Medium wane.

Small crook.

Medium cup.

Large pitch pockets which do not show an opening through the piece.

Large pitch streak.

Pitch.

Pin wormholes well scattered.

Medium discoloration.

Firm red heart.

Pith—one-sixth the length of piece.

Patch heavy torn grain.

Slight skip.

Medium cross grain.

No. 2 Common

No. 2 Common permits any number of the following defects, but no combination of them so serious as to prevent the use of each piece as a whole, except as noted:

Sound and tight knots—2½ inches in diameter in 4-inch and 6-inch widths, 3 inches in 8-inch and 10-inch, 3½ inches in 12-inch, and not over 4 inches in wider widths.
Unsound and pith knots—one-half the diameter of sound and tight knots permitted, provided the knot be fixed in position.
Spike or branch knots—which are sound and do not weaken the piece at any point more than the knots heretofore specified.
Medium split.
Through check or shake—one-sixth the length of piece.
Large wane.
Medium crook.
Large cup.
Large through pitch pockets—which do not show an opening greater than ⅛ inch wide by 3 inches in length.
Large pitch streak.
Pitch.
Small grub wormholes—maximum of one per surface foot.
Pin wormholes.
Heavy discoloration.
Firm red heart.
Advanced decay—not going through the board, equal in area to a streak ½ inch wide by one-sixth the length of piece.
Pith.
Patch deep torn grain.
Slight skips.
Heavy cross grain.

Pieces containing a loose knot or knot hole not more than 2 inches in diameter located more than 32 inches from either end may be permitted, provided the rest of the piece is of No. 1 Common quality.

No. 3 Common

No. 3 Common permits numerous coarse defects, such as:

Large spike knots.
Loose or decayed knots or knot holes.
Excessive shake, checks, or splits.
Large wane or skips in dressing.
Advanced decay or heavy discoloration.
Excessive pitch defects.
Large grub wormholes.

It shall be suitable for use as a whole, or each piece shall contain not less than 75 per cent of material of No. 2 Common quality.

When defects occasioning waste, such as loose knots or knot holes, are permitted, they shall not be present in excess of the following:

One in lengths up to 10 feet.
Two in 12 and 14-foot lengths.
Three in 16-foot and longer lengths.

No. 4 Common

The defects common to this grade are similar to those found in No. 3 Common, but exist to a greater degree.

The most common serious defects are knot holes, advanced decay or its equivalent in heavy massed pitch, and serious check. Other types are extremely coarse knotted, wany, shaky, badly split or checked.

No. 5 Common

No. 5 Common is the lowest recognized grade and admits all defects known in lumber, provided each piece is strong enough to hold together when carefully handled.

TABLE XLII.—SIZES FOR FINISHING, COMMON BOARDS, AND DIMENSION

[The thicknesses apply to all widths and the widths to all thicknesses.]

Product	Nominal size		Dressed size based on lumber properly seasoned for the use intended		Lengths
	Thickness, inches	Width, inches	Thickness, inches	Width, inches	
Finishing: S1S or S2S and S1E or S2E.	3/8	3	5/16	2 5/8	6 to 24 feet in multiples of 1 foot
	1/2	4	7/16	3 5/8	
	5/8	5	9/16	4 5/8	
	3/4	6	11/16	5 5/8	
	1	7	13/16	6 5/8	
	1 1/4	8	1 1/16	7 1/2	
	1 1/2	9	1 5/16	8 1/2	
	2	10	1 3/4	9 1/2	
	2 1/2	11	2 1/8	10 1/2	
	3	12	2 5/8	11 1/2	
		14		13 1/2	
		16		15 1/2	
		18		17 1/2	
		20		19 1/2	
		Over 20		1/2 scant	
Common boards: S1S or S2S and S1E or S2E	1	3	13/16	2 5/8	4 to 24 feet in multiples of 1 foot
	1 1/4	4	1 1/16	3 5/8	
	1 1/2	5	1 5/16	4 5/8	
	2	6	1 5/8	5 5/8	
		7		6 5/8	
		8		7 1/2	
		9		8 1/2	
		10		9 1/2	
		11		10 1/2	
		12		11 1/2	
Dimension: S1S or S2S and S1E or S2E	2	2	1 5/8	1 5/8	Do.
	2 1/2	4	2 1/8	3 5/8	
	3	6	2 5/8	5 5/8	
	4	8	3 5/8	7 1/2	
	over 4	10	3/8 scant	9 1/2	
		12		11 1/2	
		over 12		1/2 scant	

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